PAPER MAKING PROCESSES
AND
MACHINERY
BY
J. B. BENNETT

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OF
PAPER MAKING MACHINERY
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PAPER-MAKING PROCESSES
AND MACHINERY

BY

J. B. BENNETT, Assoc. M. Inst., C.E.
EDINBURGH

(*Read before the Manchester Association of Engineers*, 9*th April* 1892),

WITH ILLUSTRATIONS

OF

PAPER-MAKING MACHINERY

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INTRODUCTORY NOTE.

Being aware of the preparation by Mr J. B. Bennett, C.E., of this City, of the following notes on Paper-Making Processes and Machinery, it occurred to us that it might be interesting to some, who, from time to time, write us about Paper-Making projects, if we arranged with him for the publication of his notes in book form, accompanied by illustrations of our Machinery.

On conferring with Mr Bennett, he at once kindly agreed to the proposal, which has now been carried out. We trust that as a resumé in brief form of what is more fully dealt with in larger, but, to many, less accessible treatises on Paper-Making, these notes will be found acceptable to our readers.

BERTRAMS LIMITED.

PAPER-MAKING PROCESSES AND MACHINERY,

BY

Mr. J. B. BENNETT, Assoc.M.Inst.C.E.,

OF EDINBURGH.

(Communicated by Mr. A. REA, of Manchester, to the Manchester Association of Engineers.)

SATURDAY, 9TH APRIL, 1892.

ANTIQUITY OF PAPER MAKING.

The art of making writing material from vegetable fibres has been practised from very ancient times, although it is not of such great antiquity as weaving or the manipulation of the more ductile metals, but curiously enough, some of the ancient civilised nations, such as those resident in Mesopotamia, appear to have been ignorant of it. The earlier processes were, no doubt, of a purely mechanical character, consisting chiefly in the beating out to a uniform surface the compact tissues of the bast or inner bark of trees and plants. A process of this nature is still in use in Japan, where one form of the soft Japanese paper, with which we are now so familiar, is prepared by the most primitive means from the bast of a species of mulberry, which is simply cut into pieces and hammered out to produce a surface of the requisite evenness.

Of more complex processes, the earliest of which we have any record is that of the manufacture of papyrus from the paper reed as practised in Egypt. Egyptian papyri dating back to 2000 years B.C. have been preserved.

The use of papyrus was very widely spread in the ancient world. It is known to have been used in Greece 400 B.C., and in Rome itself, under the Empire, a manufacture of some kind connected with papyrus was carried on, though it is probable that this was the production of larger and stronger sheets by the union of the smaller sized sheets of different qualities rather than the manufacture of the material itself, which would appear to have been exclusively confined to Egypt.

MANUFACTURE OF PAPYRUS.

Pliny, in his Natural History, has preserved for us an account of the manufacture of papyrus, from which it would appear that the stem of the reed was first cut into longitudinal strips by a sharp knife, those from the centre of the plant being the broadest and most valuable. These strips were laid on a board side by side to the required width, thus forming a layer, above which another layer of shorter strips was laid at right angles. These two layers thus woven formed a sheet which was soaked in water. It is not quite clear from Pliny's description whether some peculiar property of the Nile water acted as a solvent upon some glutinous matter contained in the material itself which caused the layers to adhere, or whether a paste was actually used, but be this as it may, the sheet thus formed was finally pressed and dried in the sun, any roughness being removed by polishing with ivory or a smooth shell. The papyrus sheets thus produced were very small, being barely 10ins. in breadth, but sometimes the finer sheets were joined together with a backing of a coarser quality, producing sheets up to 18ins. wide, and these sheets were again joined together by pasting the edges to form rolls. Papyrus continued in use in many parts of Europe for a long period, and even in the tenth century it was used exclusively for Papal Bulls, but after the twelfth century its use almost wholly ceased, vellum and pulped paper being used instead.

PAPER MAKING FROM FIBROUS SUBSTANCES.

The art of making paper from fibrous substances reduced to a pulp appears to have been first known to the Chinese, who certainly practised it in the first century A.D., employing, among other materials, the wool of the cotton plant. It was not, however, until the eighth century that pulped paper became known to the western world, its introduction being due, like a great many other useful arts, to the Arabs, who probably acquired it from the Chinese at the capture of Samarcand in A.D. 704. At all events, the manufacture was taken up by them in that city and gradually spread through all parts of their empire. Large quantities of it were produced for a long time in Damascus, and imported through Greece into Europe, where, during the middle ages, one of the names for paper was *Charta Damascena.*

The manufacture of cotton paper in Europe was, as was natural, first established in those countries which were most in contact with Oriental influences, as in Spain by the Moors, and in Italy through the Arab occupation of Sicily. As the industry spread further north to districts where cotton was not to be found as a natural product and was not imported, other substances had to be pressed into the service. Hence arose the use of rags, first woollen, then linen, which extended until linen and flax fibres formed the staple material. The earliest notice we have of rag paper is a reference in a work of the twelfth century, in which woollen rags are probably meant. Linen paper was first made in the fourteenth century, when paper-making had become an established industry in northern Europe, and about the same period, according to some authorities, water-marks were first introduced, the Oriental papers not having had any. Mills were started in Germany in the fourteenth century, and in Holland a little later, and by the middle of the fifteenth century the use of paper for all literary purposes had gradually superseded vellum.

PAPER MAKING IN BRITAIN.

Paper was in very general use in Britain at the beginning of the fourteenth century, but there is no evidence that it was manufactured in this country before the beginning of the sixteenth century; one, Tate, who set up a mill at Hertford about that time, being the first known paper-maker in England.

Paper-making does not appear to have been introduced into Scotland till 1675, when a mill was set up near Edinburgh, on the water of Leith, but there is reason to conclude that this mill was not continued, and the manufacture of paper in Scotland was not successfully begun until the middle of the eighteenth century.

MATERIALS REQUIRED FOR MAKING PAPER.

Down to 30 years ago, rags—cotton and linen—and mill wastes formed the staple material of paper-making; but the largely increasing demand for paper has led manufacturers to look to other sources for the bulk of their raw materials. It has been said that the paper industry subsists upon the rejecta of the textile manufactures, but as paper-making requires that the raw materials shall be reduced to the condition of minute sub-division of the constituent fibres, it can, in addition, avail itself of materials which are valueless to the spinner, and paper is now made from a great variety of fibres. Chief among these in Great Britain are esparto and wood pulp, which may now, rather than rags, be considered the staple paper-making materials.

ESPARTO PULP.

Esparto grass, the leaves and shoots of which are the parts used, is a native of the south of Spain and the north of Africa, and grows in patches to a height of from one to three feet. It has been in use for centuries for ropes, baskets, matting, &c., on account of the strength of its fibre combined with its lightness, hawsers made of it being so light as to float on water. For paper-making esparto was first utilised by the French, but in 1856 it was first used in England, and in that year ten tons of it were imported. In 1857, Mr. Routledge, of the Eynsham Paper Mills, near Oxford, began to use esparto systematically on a small scale, and the process gradually developed.

In 1861 the Board of Trade first separated esparto from other paper-making materials in their return of imports, and set down 891 tons as the quantity brought into the country. Its use was favoured by the outbreak of the American Civil War, and the consequent scarcity of cotton, and the imports of esparto rose to 20,062 tons in 1863, and 55,726 tons in 1867. They have gone on steadily increasing since, and at the present time upwards of 180,000 tons, of a value of over £1,000,000 sterling, are annually imported into this country.

WOOD PULP.

Wood-pulp, imported into Britain chiefly from Norway and Germany, has been largely used of late years in the manufacture of the cheaper papers. This pulp is prepared either chemically, or mechanically by grinding, and the chemical processes, of which there are several, produce a pulp of excellent quality. Mechanical wood-pulp has the advantage of being cheap, but paper containing it is very liable to become discoloured by the action of air and light, and the fibre is, moreover, devoid of much felting power, and has little in fact to recommend it but its comparative cheapness. It is, nevertheless, used in large quantities, some cheap papers being made entirely from it.

The manufacture of wood pulp from white pine timber has increased in Norway from about 20,000 tons in 1880 to 150,000 tons in 1887, and during the last five years there has been a great augmentation. It is said on good authority that more than two-thirds of all the wood-pulp made in Scandinavia is imported into Great Britain. Wood-pulp is largely used in America, but there poplar wood chiefly forms the raw material, and it is claimed that it gives better results than pine.

STRAW PULP.

Straw has been used for paper-making for many years, and a book was printed in London in 1801 on paper made wholly from straw, but in general this material is mixed either with rags or esparto, as it produces a very brittle paper when used alone. Many other fibres are employed in paper-making, among which may be mentioned jute and hemp—chiefly in the form of sacking and old ropes—for brown paper, peat, bamboo, sugar-cane refuse, China grass, sunn, pine-apple, New Zealand flax, yucca, aloe, and the common nettle, which possesses a strong fibre somewhat akin to flax, but the use of some of these is chiefly by way of experiment and calls for merely passing notice.

INDIAN GRASSES.

Of recent years several paper mills have been established in India, chiefly for the manufacture of the commoner papers from jute. Some of these mills are large and successful, paying dividends from 10 per cent. to 16 per cent. per annum over a course of years. Some of the Indian newspapers ask: Why should not India ere long supply paper to Europe as it now supplies manufactured jute? But owing to the cost of chemicals, coals and transport, it is not likely that paper could be exported to Europe at a price to compete with home manufactures.

Experiments have also been made in the use of rhea grass with the object of establishing mills in Australasia, but they have not as yet been very successful.

PROCESSES NECESSARY FOR PAPER PRODUCTION.

While the processes necessary for the production of paper vary much in detail according to the nature of the materials employed and the class of paper intended to be produced, they are all based upon the same general principles, and they may be divided into three main groups: First, the complete separation of the fibrous parts of the raw material from the cellular portions which, combined with them, go to make up the entire plant; second, the reduction of these fibres to the condition of a fine pulp; and third, the transformation of this pulp into paper.

It is evident that those materials, such as bleached cotton and linen thread and rags, which have already undergone treatment by the textile manufacturer and in which the fibres are therefore more or less completely isolated, require but little chemical treatment at the hands of the paper-maker, whose attention is therefore chiefly directed to the removal of such substances as size, grease, etc. In other raw materials, such as esparto, straw and wood, there are in addition to the fibrous compounds which form so to speak the groundwork of the material, a certain proportion of silica, also gummy and resinous matters, the removal of which has to be brought about.

PICKING AND SORTING.

The first stage in the process of manufacture is that of picking and sorting the raw materials. In the case of rags, which vary greatly in quality, from clean, almost unused, portions to the very foulest descriptions, the first thing to be done is to sort and cut them into pieces of a convenient size.

The cutting may be done either by machine or by hand, but the latter is preferred by many manufacturers, especially for the finer classes of paper, as by it more perfect removal of impurities can be effected. This work is almost invariably performed by women, who stand at tables into which broad knives are fixed. Each worker is provided with a number of boxes, into which the different qualities of rags are put. The sorting is done on purely arbitrary lines, the colour and the material of which the rags are composed being the guiding features, and all foreign substances, such as buttons and hooks, are carefully removed.

A rag cutting machine is very simple; the material is passed along a table at the end of which is a fixed knife, beside which is a revolving drum carrying three or more knives on its rim, and as the rags are pushed forward they are caught between the knives and cut up. A similar machine is also used for chopping up ropes.

For the removal of dust and all loose extraneous matter, the rags are generally passed through a machine known as a combined willow and duster. In the willow there are two revolving drums with teeth by which the rags are beaten, after which they are passed into the duster, which slopes, so that, as it revolves the rags travel along and are discharged at its lower end, and the frame being also fitted with teeth, the dust is pretty well driven out by the time the rags are discharged from it.

Raw fibres, such as esparto and straw, are passed through a similar machine and are also subjected to a preliminary picking process, all root ends and weeds and other foreign substances being carefully removed. This is known as dry picking, to distinguish it from a subsequent picking which the material sometimes undergoes after it has been boiled.

BOILING.

Rags, straw, ropes and waste for the commoner classes of papers, are generally boiled in spherical boilers which are made to rotate and thus circulate the liquor, the lye and steam being admitted through hollow journals.

The class of boiler used for esparto is an upright fixed boiler constructed upon what is known as the vomiting principle. In this boiler the steam is admitted from the top by a pipe, which passes right down the centre inside a larger tube and through the false bottom of the boiler, and by its action the lye which has percolated through the grass in the boiler to the space below the false bottom is forced up the wide pipe, and striking against the dome at the top is distributed over the surface of the grass. In this way a constant circulation of the lye is kept up.

Several patent boilers on this vomiting principle have been introduced. Of these Sinclair's is perhaps as well known as any. It has two vomiting pipes made of thin steel plates and rivetted to the sides of the boiler. The liquor when forced up the vomiting pipes is distributed through perforated plates over the grass in a number of fine jets. In Roeckner's patent boiler, another modification, the vomiting pipe is outside the boiler.

The alkali employed in boiling, which is necessary for the removal of the resinous matters contained in the raw material, may be in the case of rags, caustic lime, caustic soda or carbonate of soda, but in the case of esparto and of straw, caustic soda is alone used, as lime forms insoluble compounds with the non-cellulose portions of the grasses. The proportion of caustic soda used is about 10 per cent. of the dry weight of the raw material, and this is first dissolved in water and introduced as a lye into the boilers. The steam is used for the purpose of raising the temperature, the necessary circulation of the liquor being produced in the manner already described. It is found that it is possible by increasing the pressure of the steam to do with a smaller proportion of caustic acid, or *vice versa*, and to such an extent can this be carried on, especially with esparto, that in some mills this material is boiled in open vessels with, of course, a very strong lye.

The pressure of steam in esparto boilers varies from 10 to 45lbs. per square inch, and there is a growing tendency to adopt higher pressures, even up to 70lbs., on account of the economy of soda effected, although a little fibre is lost. The time occupied in boiling varies from two to ten hours according to the material, the chemicals used, and the pressures.

When the boiling is completed the pressure of steam is allowed to fall, and the waste liquor drained off; the contents of the boiler then receive a preliminary washing with clean hot water. The quantity of water should be kept as small as may be, more especially in cases where it is necessary to evaporate the whole of the waste liquors, and it is the practice in some mills, *e.g.*, in in some of those on the River North Esk, in Midlothian, to wash the grass in a series of tanks connected together in the same way as the lixiviating tanks of an alkali works. They are so arranged that pure water flows in at one end, passes through fresh lots of grass in succession, and issues at the further end highly charged with the soluble products of the grass, and this final washing is sometimes used to dissolve the soda for the lye. By such an arrangement the grass can be washed without any loss of fibre, and with a minimum quantity of water.

After the washing, the fibres are removed into convenient receptacles, generally iron boxes on wheels, and are taken to the breaking engines.

(Note.—The process of Soda Recovery is alluded to at the end of this paper.)

WASHING AND BREAKING.

The boiling process has removed all cell substances and fibres only remain. These have now to be pulped, and they are, first of all, placed in what is termed the washing engine or breaker. This engine is an oblong vessel of cast iron, with rounded ends, and is made in many sizes, from about twelve feet long by six feet broad and two feet deep, upwards. The smaller sizes are usually cast in one piece, but within recent years it has been made in sections of cast iron plates securely fitted together to any desired size. Messrs. Bertrams Limited, of Edinburgh, have made these engines up to over 24ft. long, and the working results have been remarkably successful.

In the centre is a partition or "Midfeather" which, however, does not reach to either end. In one of the compartments is placed a roll about three feet in diameter, or larger according to the size of the engine, which is provided with knives arranged parallel to the axis in groups all round it. In the bottom of the vessel immediately underneath the roll a bed-plate provided with similar knives is placed, but they do not lie parallel with those of the roll, and in this way the action of a pair of scissors is imitated to some extent.

The roll is made to revolve rapidly, and by its action the fibres are made to pass between it and the bed-plate, where they are caught and broken up by the knives. It will be easily seen that the action of the roll causes the pulp to travel constantly round and round the vessel, and advantage is taken of this to wash thoroughly away all traces of the lye with which it was boiled. The dirty water is removed by means of a revolving drum washer covered with fine wire cloth, containing scoop-shaped blades inside which lift the water and throw it upon the hollow axle of the drum, through which it runs to waste, its place being supplied by a constant flow of clean water into the breaker.

BLEACHING.

When the pulp is thoroughly washed, it is bleached, and this is usually done in the breaking engines, though frequently the operation is performed in special engines resembling breakers, termed potchers.

The bleaching medium usually employed is a solution of chloride of lime (bleaching powder) in water, prepared in a vessel provided with stirrers or agitators whereby a thorough mixture of the bleaching powder and water is obtained.

The amount of bleaching powder necessary varies very much with the fibre, but in well-boiled pulps it may be taken that esparto requires 10 per cent. to 15 per cent. of its weight before boiling, straw 7 per cent. to 10 per cent., and wood 15 per cent. to 20 per cent. This method of bleaching by solution of chloride of lime is the one in general use, but others, such as the use of chlorine gas and of acetic acid, have been adopted.

Various attempts have been made from time to time to bleach textile fabrics and paper pulp by means of electricity, or to speak more correctly, by means of solutions which, containing alkaline chlorides in such small quantities as to be practically useless for bleaching purposes, have their contained chlorine so acted upon by the decomposing action of an electric current as to render them efficient bleachers. Inventors have proved that pulp can be bleached by such processes, but up till now have failed to convince manufacturers of their utility and economy.

PREPARATION OF WOOD PULP.

The process of preparing wood pulp, which is only carried on in this country to a very limited extent, ought here to be referred to. Mechanical wood-pulp is obtained by disintegrating wood by mechanical means alone, no chemical being employed. The wood is first cut into blocks and any knots present are cut out. The stones by which the blocks are ground down are made of a hard sandstone, of which only one quadrant is exposed for use, the remaining three being covered by an iron casing. The surfaces of the stones are kept rough by the pressure of steel rolls studded with points which are pressed against them while revolving, and in addition channels about ¼inch deep are cut into the stone at distances of two to three inches. These serve to carry off the pulp to the sides of the stones, in addition to giving increased grinding power. The pressure of the blocks of wood against the stones is steadily maintained by screws worked by suitable gearing. This is necessary in order to obtain a pulp of uniform character. A stream of water is kept constantly playing on the stone, and by this means the pulp is carried away as fast as it can be formed.

Chemical wood-pulp is somewhat difficult of preparation, it being necessary to boil the wood at temperatures corresponding to pressures of six to ten atmospheres ; and as the use of strong caustic soda solutions at high temperatures is attended with very serious objections, apart from the question of cost, various processes have been from time to time proposed in which the hydrolytic agent is a solution of sulphurous acid in water, either alone or in combination with a base. These latter are the processes generally used, but their details need not be entered into here.

THE PRESSE PÂTE PROCESS FOR HALF STUFF.

The broken and bleached pulp, termed half stuff, is not yet sufficiently disintegrated for paper-making. If this were attempted the paper produced would be found wanting in evenness of texture and uniformity of surface, and the pulp has therefore to be subjected to still further treatment. It has become customary during late years, especially in the case of papers in which esparto or straw is the staple material, to treat the half stuff by what is termed the " Presse Pâte " process. This is in effect the conversion of the half stuff into a web on what is practically the wet end of a paper machine (afterwards described) and it has the advantage that the straining the pulp receives secures the complete removal of all hard unboiled portions of the fibres, and enables manufacturers to dispense to a great extent with the costly processes of dry and wet hand-picking. It also permits of the more thorough removal of the products of the action of the bleaching powder.

BEATING.

The pulp from the presse pâte machine, or the half stuff from the breakers, is now removed to the beaters. These resemble very much the breakers already described, the chief difference being that the roll carries a larger number of knives and that it is brought into close contact with the bed-plate, by which means the half stuff is converted into fine fibrous pulp ready for the paper-making machine. The pulp remains in the beaters subjected to the action of the knives for a period of from four to six hours, and too much care cannot be given to this operation.

The length of the fibre to which the pulp should be reduced depends to some extent upon the kind of paper to which it is to be applied.

Messrs. Cross & Bevan state that they found the dimensions in millimetres of various pulps to be as follows :—

Fibre.	Maximum.	Minimum.	Mean.
Cotton	1·32	0·23	0·75
Linen	1·20	0·20	0·76
Esparto	1·40	0·40	1·00
Straw	1·50	0·50	0·88
Wood	2·60	1·00	2·00

(1 millimetre = practically $\frac{1}{25}$ inch.)

It is usual, except in the case of papers of the very highest quality, to add to the pulp a quantity of some cheap loading material, such as China clay, or pearl hardening, that is sulphate of lime. The addition of clay in moderate quantities serves to fill up the pores of the paper and enables it to take a good surface, and also enables the manufacturer to meet the demand for cheap paper, but when it is added to the extent of 20 °/o to 25 °/o it cannot be to the advantage of the consumer, and must be regarded as an adulteration.

FILLING UP INTERSTICES FOR WRITING OR PRINTING PAPERS.

Papers that are intended to be written upon with ink, and also most printing papers, require to have the interstices of the fibres filled up with some material which will to a greater or lesser extent resist the action of water, and thus prevent the ink or other liquid applied to them from running. This may be accomplished in two ways, either by adding to the pulp in the beater a mixture of resin with soda and starch, in which case the paper is termed engine sized ; or after the paper is made it may be passed through a vessel containing a solution of gelatine, and afterwards dried by passing over a large number of light sparred rollers, and in this case it is termed tubsized.

Blotting paper and filter papers, which are unsized papers, are made with the addition of starch only, which binds the fibres together to some extent, while not preventing the paper from being absorbent.

COLOURING.

The fibres used for paper-making, except in very rare instances, are never sufficiently white of themselves to produce a perfectly white paper, and it is necessary to complement the slightly yellow colour which most pulps possess after bleaching by the addition of small quantities of blue and pink colouring matters, ultra-marine and smalts being the best blues, and cochineal the best red for this purpose, though aniline dyes are sometimes used. Papers of any desired colour or mottled colours may be made either by using rags previously dyed, or by adding to the bleached pulp in the beaters such colours as will obtain it, and any colour which can be obtained in the form of a fine powder or of a solution will suffice. The pulp having been beaten to the required fineness, loaded, coloured, and if necessary sized, is now run from the beaters to the stuff chests ready to be made into paper.

MODES OF MANUFACTURING PAPER.

So recently as the end of last century all paper was made in single sheets by hand, the paper-machine being, comparatively speaking, of recent invention, and still the best qualities of paper, especially of drawing paper, are hand-made.

MAKING BY HAND.

To form a sheet of paper by hand the workman takes a mould of wire-cloth with a moveable frame of wood called a deckle fitted all round it and extending slightly above its surface, and dips this mould into a vat containing the prepared pulp diluted with water, lifting up as much as will make a sheet of the necessary thickness. When the mould is removed from the vat the water drains through the wire-cloth, leaving the fibres on the surface, and the felting or intertwining of the fibres is assisted by lateral motion in every direction given by the workman to the mould. The deckle is then removed and the mould with the sheet of paper handed over to another workman, who turns it over on to a sheet of felt, by this means transferring the sheet of paper from the wire to the felt. The sheets thus formed are piled together alternately with pieces of felt, and when a sufficient number have been made they are subjected to strong pressure to expel the water. The felts are removed and the sheets receive a second pressing. They are then sized by being dipped into a solution of gelatine, again slightly pressed, and finally hung up on lines made of horse hair to dry. If they are to have a smooth surface they are pressed through a calender.

Any pattern or name required on the paper, known as a water-mark, is obtained by means of a slightly raised pattern formed on the wire cloth, the consequence of which is that less pulp lodges there and the paper is slightly thinner, showing the counterpart of the pattern when held against the light.

MAKING BY MACHINE.

The paper-making machine is the invention of a workman named Robert, employed in a paper mill at Essones, in France, by M. Francois Didot. Didot set the apparatus to work, and Robert obtained a grant of 8,000 francs from the French Government and a patent for fifteen years. This was in 1799. In 1801 Didot came over to this country, and after obtaining two British patents sold them to Messrs. Fourdrinier, with whose name the machine is generally associated. A workshop in Dartford, in Kent, was selected as the place for making the machines, under the special care of Mr. Bryan Donkin. In 1803 a model of a self-acting machine was set up, in 1804 the system came successfully into use, and now there are in Great Britain about 550 paper machines at work, each producing probably on an average 20 tons of paper a week. One of the first engineering establishments in the world for building machines for paper-making is Messrs. Bertrams Limited, Sciennes, Edinburgh. This firm was founded over 70 years ago, and as an instance of its progress it may be mentioned that it turned out twelve paper-making machines in 1890, besides a large amount of general work, a production which has been hitherto unequalled by it or any other firm.

The paper-making machine of the present day, though embodying many ingenious improvements, differs little in principle from that originally constructed by Fourdrinier. It consists essentially of an endless wire-cloth mould on to which the prepared pulp flows, and on which a continuous sheet of paper is formed. This is then passed through a series of rollers to expel the water, and over a number of heated cylinders to be dried, and is wound up at the end of the machine as finished paper.

The receptacles into which the pulp is passed on leaving the beaters are known as the stuff chests. They are provided with stirrers or agitators which continually revolve and keep the pulp constantly mixed with the diluting water.

From the stuff chests the pulp is pumped up into a small regulating box so constructed that the pulp in it remains constantly at the same level, thus insuring that the discharge of pulp on to the machine shall be uniform.

From this regulating box the pulp flows on to one end of a long shallow trough, termed a sand table, which is laid so that the pulp travels along it at a slow speed, allowing in its passage all particles of sand or dirt to fall to the bottom. In some mills these sand tables are 200 yards in length.

After leaving the sand tables the pulp passes through the strainers, which consist of strong brass or bronze plates with a number of very fine slits cut into them, and which remove all lumps formed by the intertwining of the fibre thus preventing inequalities in the finished paper. The slits vary from two to three inches long, and from about $\frac{1}{120}$ to $\frac{1}{20}$ of an inch in width. The strainers, when of the jog or cam motion type, receive a violent shaking motion to assist the passage of the fibres through the slits. But strainers with indiarubber suction diaphragms and revolving strainers are now much used.

From the strainers the pulp is passed on to the end of the wire-cloth, which is generally from 35 to 50 feet long and even as long as 60 feet in special cases, carried on a large number of small rolls. At each side is a strap of indiarubber, known as the deckle strap, which regulates the width of the paper. As the pulp travels along the wire the greater part of the water drains away, and passes into what is known as the save-all, but as this water contains a considerable quantity of the finer pulp particles, size, etc., it is pumped back again to the upper end of the sand tables and there used to dilute fresh pulp.

After the pulp has travelled about three-fourths of the length of the wire it passes over what are known as suction boxes, in which a vacuum is created by means of pumps (generally arranged in sets of two to six), and here the larger part of the remaining water is removed. The paper has now the consistence of wet blotting paper.

It then passes on the wire through a pair of rolls known as the couch rolls, which serve to press out water from the paper and to detach the paper from the wire. The paper is now received on to an endless felt, and passes through a pair of iron or brass rolls, known as the first press rolls. In doing this, one side being in contact with the metal roll is rendered comparatively smooth while the other retains the impress of the felt, and to make both sides alike the paper is passed through a second pair of press rolls, in which the side formerly in contact with the felt is brought in contact with the metal roll, and both sides of the paper are thus made alike. Sometimes the bottom press roll is covered with indiarubber to economise the felt.

After leaving the press rolls the paper is carried over the drying cylinders, which are heated with steam at a low pressure, from 2½ to 20 pounds to the square inch. These may vary in number from eight to fifteen or twenty-two, each four feet in diameter, and are generally arranged in two groups, between which is placed a pair of chilled iron rolls, known as smoothers, and whose use is sufficiently indicated by the name.

If the paper is intended to be separately calendered it is now wound upon a reel and removed to the finishing house, but there is now a considerable demand for what are known as machine-finished papers, and there are therefore frequently attached one, two, three or four stacks of calenders to the end of the machine, by which the paper may be finished ready for use.

In some cases where an extra finish is desired, arrangements are made after the paper leaves the drying cylinders for passing it through damping rolls, where it is sufficiently wetted to enable it to take a high finish when passed through the calenders.

FINISHING PAPER AFTER LEAVING THE MACHINE.

The finishing house of a paper mill is fitted with calendering machines, which may either be web calenders for glazing continuous rolls or plate calenders for glazing single sheets, the latter being the type used for highly finished paper. Still higher degrees of finish are imparted by friction glazing, as for envelope papers, when wax is introduced in the process ; also enamelled papers for special purposes.

There are in the finishing house cutting machines for cutting the webs up into sheets of different sizes, some of these machines being constructed to cut from as many as seven webs at one time. This class of cutter was first introduced by the late Mr. George Bertram, whose son, Mr. D. N. Bertram, is now Acting Director of Bertrams Limited.

The sheets are then sorted by hand, all damaged ones removed and the paper packed up and sent to market.

MACHINERY REQUIRED FOR MAKING PAPER.

The machinery necessary in a mill depends, of course, upon the quantity but quite as much upon the quality of paper intended to be made. Thus a mill with one paper-making machine to produce say 25 to 30 tons of a high-class writing or printing paper per week wholly from raw material, such as esparto, would require to be capable of dealing in the boiling with about 50 tons of esparto per week, and so would require two grass boilers.

For breaking there would be needed four large breaking engines, from which the half stuff would pass to the stuff chests of the presse pâte.

From the presse pâte the half stuff would be taken to the beaters, of which there would also be four of the large size.

Paper machines vary in width of wire from about 60 to about 126 inches, and the quantity of paper which can be produced on any machine may be said to be governed by the quality and the thickness of paper, the width of the wire and the heating power of the cylinders, because the greater the heating power the more rapidly can the paper be allowed to travel along the machine and, of course, the same course can be followed when a light paper is being made. Paper machines are therefore fitted with change wheels and also large tapered cones by which the speed can be regulated, and it may usually be varied from 30 to 200 feet per minute, and in the case of thin news paper to as much as about 250 to 300 feet per minute.

For steam power to drive such a mill Lancashire boilers working say at 80 to 100 pounds pressure and capable of supplying steam for about 450 indicated horse-power would be necessary.

The washing and beating engines would be best driven by one large compound engine of about 250 indicated horse-power, with a main shaft from which each washer or beater would be driven by a belt. The paper machine would be driven by a separate engine, or better still by two separate engines, one for the body of machine controlling the main line of paper, and the other to drive the back shafting for pumps and agitators of stuff chests, etc. Another engine would be required to drive the presse pâte, and smaller engines would also have to be provided to work the calenders, cutting machines, hoist, etc.

ARRANGEMENT OF PAPER MILLS.

A very great deal can be done in planning a mill to conduce to economy in working, and many schemes are adopted to suit special circumstances. For instance, the whole raw materials may be lifted by a hoist to the upper floor of a mill. The grass, in this case, after being picked, passes in at the top of the boilers, and after being boiled is withdrawn at the bottom to a floor on a lower level. Here, if necessary, it is wet picked, and passed to the breakers on the same level, the half stuff from which, after being bleached, flows down by gravitation into the stuff chests of the presse pâte. From these it is pumped up to the presse pâte machine, which in this case is on the same level as the beaters, and to which the pulp is removed in boxes on wheels. The beaters are generally placed on a slightly lower level than the breakers, so that if necessary the half stuff may flow directly into them from the breakers, without being passed over the presse pâte. The stuff chests of the paper machine are on a lower level than the beaters, so that the pulp again flows by gravitation into them, and the finishing house is generally on the same level as the machine house to avoid hoisting up the finished webs.

Each case, of course, presents special circumstances and must be dealt with on its merits. The principal points to be considered in choosing a site for a paper mill are the quality and quantity of the water supply, the facility with which the waste waters can disposed of and the ease with which workers can be obtained, besides, of course, facilities of communication with markets for raw materials, chemicals, coals, and facilities for the transport of the finished paper.

WATER SUPPLY.

On the water supply the success of a mill may be said almost mainly to depend, 40,000 to 50,000 gallons of water being required for each ton of paper manufactured. Impurities in which iron forms an ingredient render a water supply very unsuitable for paper-making, but it is an unsettled point whether the presence of lime is objectionable or not.

For boiling and bleaching purposes it is objectionable to a certain extent, as giving rise when mixed with caustic soda or bleaching powder to precipitates of carbonate of lime, which form a hard scale on the inside of boilers and breakers, and this is liable to become detached and to find its way into the finished paper.

A somewhat curious instance of the effect which water has upon paper manufacture was mentioned to the author some time ago by a paper-maker in the west of Scotland. He had been in the habit of using water from a stream, which was collected in large settling ponds that the impurities might settle; but the supply being very abundant, and capable, if used in driving a turbine, of giving driving power equal to 40 horse power, he resolved to sink a well and use the water from this well for paper-making purposes. This he has done, with the result that he is now able to produce paper of a very much better colour than when he used the stream water, but he is met with the difficulty of matching the colour of paper which he formerly made, orders for which for such purposes as magazine printing were only partially complete, and this difficulty he found considerable.

EVAPORATION OF LIQUORS.

The getting rid of the liquors also sometimes presents considerable difficulties, as in the case of paper-mills on the North Esk. The usual plan adopted is to collect the washings from the boilers and the spent lye into tanks, reduce their bulk by evaporation until they are of a strength of about 15° Twaddle, then burn off the woody and fibrous matters which they contain, and thus recover the carbonate of soda, which re-causticised by the addition of lime, is used along with the addition of a small quantity of fresh caustic soda, in the boiling of fresh grass.

Various evaporators have been introduced, some of them very primitive, consisting perhaps only of a furnace for incinerating the residue, and over it a pan containing the liquor, the latter being heated and evaporated by the heat from the furnace. With such an arrangement a large quantity of heat is wasted, and various patent evaporators have been introduced. It used to be considered that the most economical evaporator was that invented by M. Porion, a French distiller, and named after him. In this the liquor is run into a chamber in which a number of cast iron fanners dip into the liquor and revolve at the rate of about 300 revolutions a minute, producing and filling the chamber with a very fine spray, and presenting a very large evaporating surface.

Recently a method of evaporating *in vacuo*, invented by Mr. H. J. Yaryan, of Toledo, Ohio, U.S.A., has been considerably developed and has been largely used for the recovery of soda.

The other waste liquors are generally purified by simple downward filtration through ashes, and in some cases where the finer papers are made the washings from the machines, which contain a large proportion of fibre, are saved, and the residues dried and disposed of to the makers of brown papers.

CONCLUSION.

The subject of paper-making processes and machinery is such a very extensive one that to deal with it effectually a volume not a paper, would be necessary, and therefore in this paper it has only been possible to give a mere outline, and the author desires to acknowledge his indebtedness to Messrs. Cross and Bevan's "Test Book of Paper-Making" for much of the information here made use of.

ILLUSTRATIONS

OF

Paper-Making Machinery

MANUFACTURED BY

BERTRAMS LIMITED

(SUCCESSORS TO GEO. AND WM. BERTRAM)

ENGINEERS

ST KATHERINE'S WORKS, SCIENNES,

EDINBURGH.

The Illustrations are reduced from our large Descriptive Catalogue, which can be had by intending purchasers on application.

PARTICULARS OF OTHER MACHINES FOR PAPER MAKERS NOT ILLUSTRATED HERE CAN BE HAD BY SPECIAL ARRANGEMENT WHEN DESIRED.

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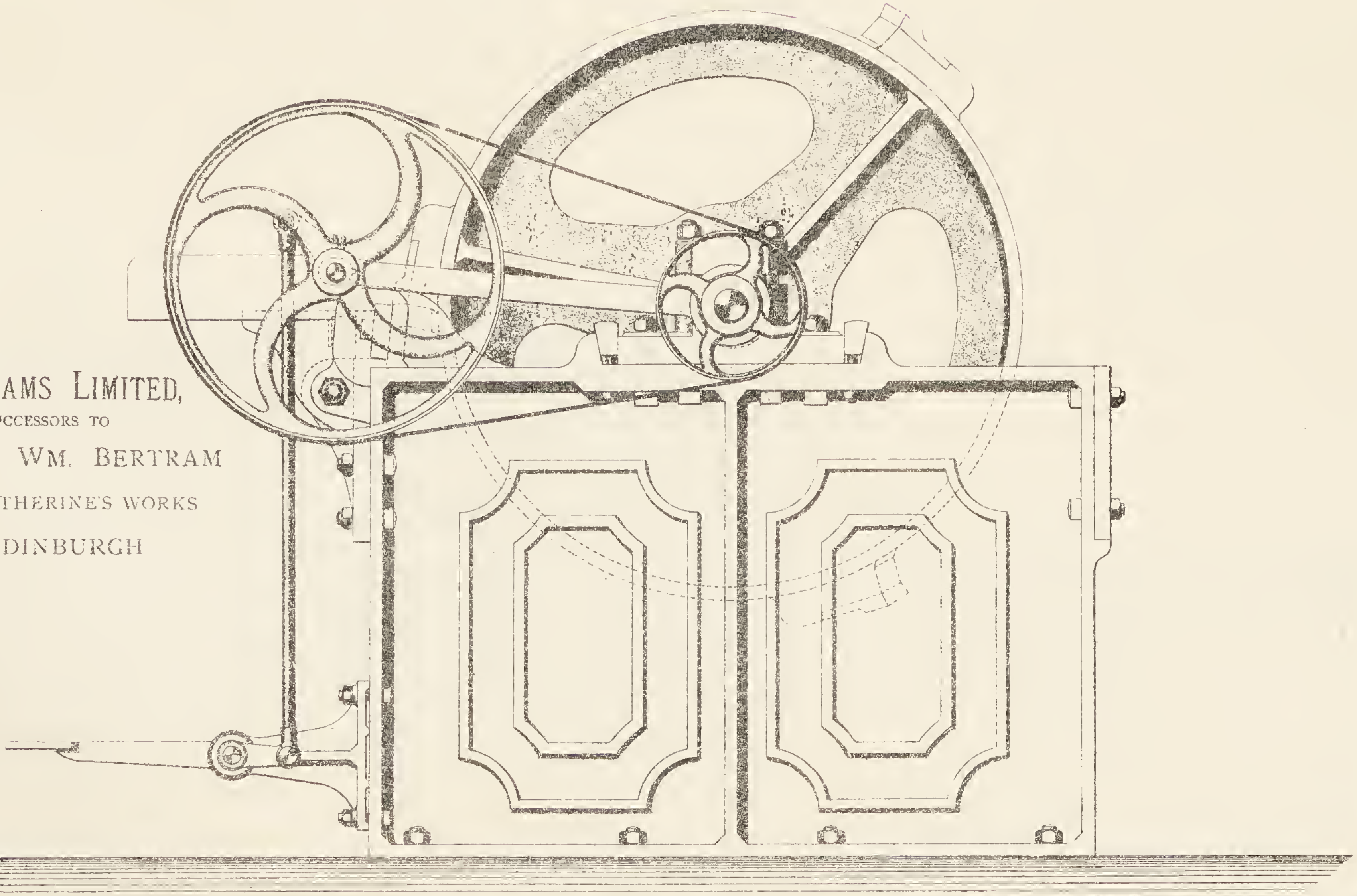
No. 1

RAG OR ROPE CHOPPER

OF THE MOST SUBSTANTIAL CONSTRUCTION



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No. 2

COMBINED WILLOW AND DUSTER

SUITABLE FOR ALL ORDINARY FIBRES

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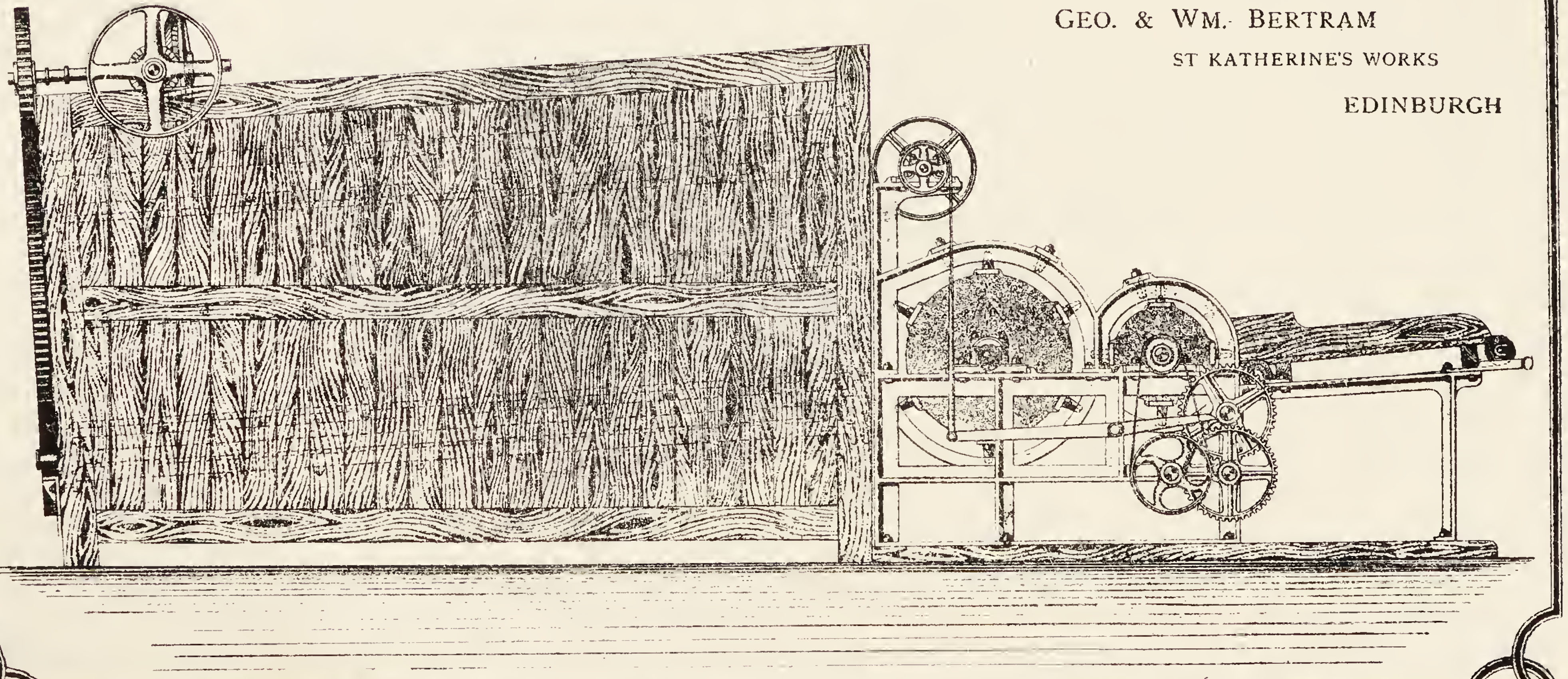
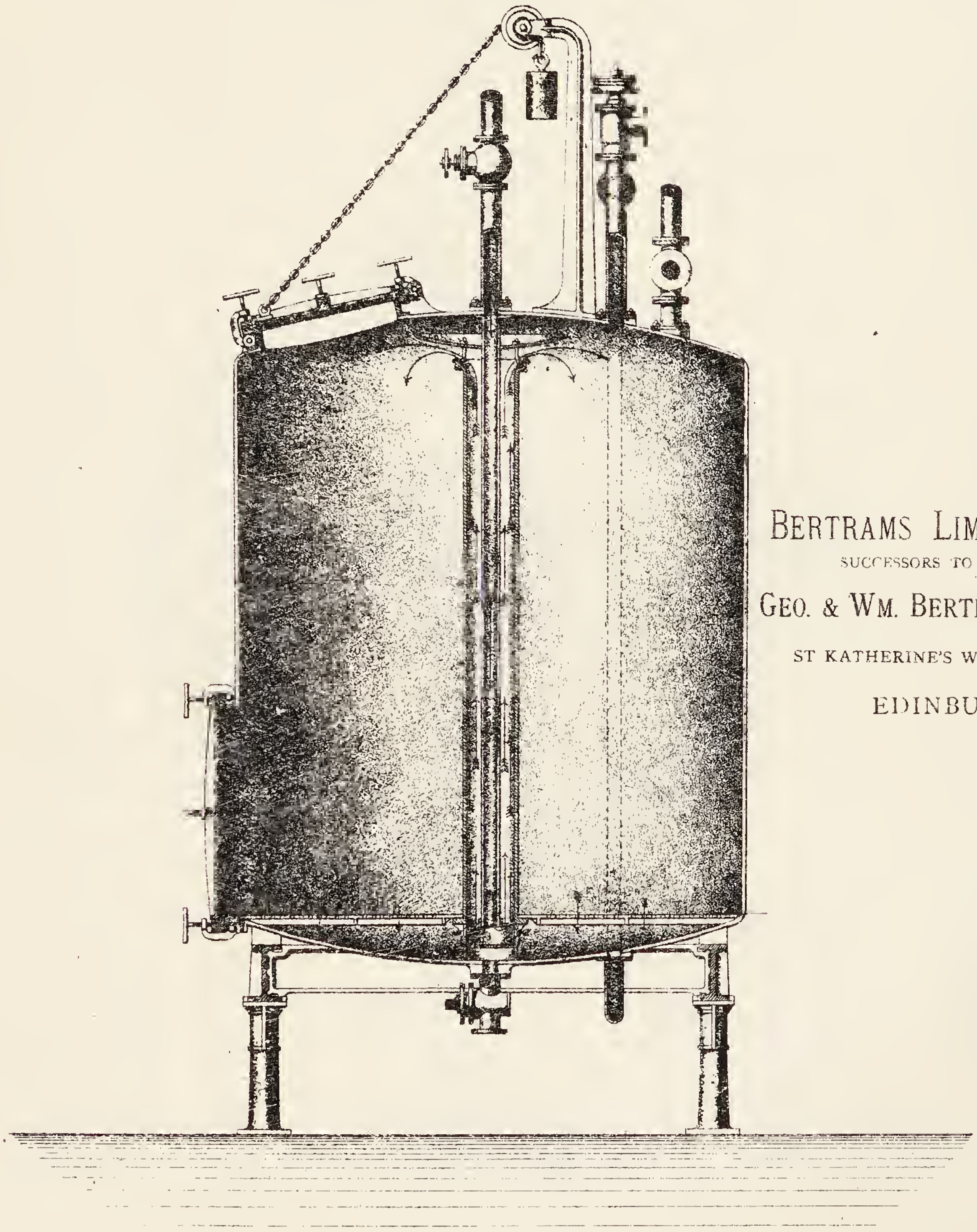


No. 3

MALLEABLE IRON, RAG OR ESPARTO BOILER

ON THE VOMITING PRINCIPLE



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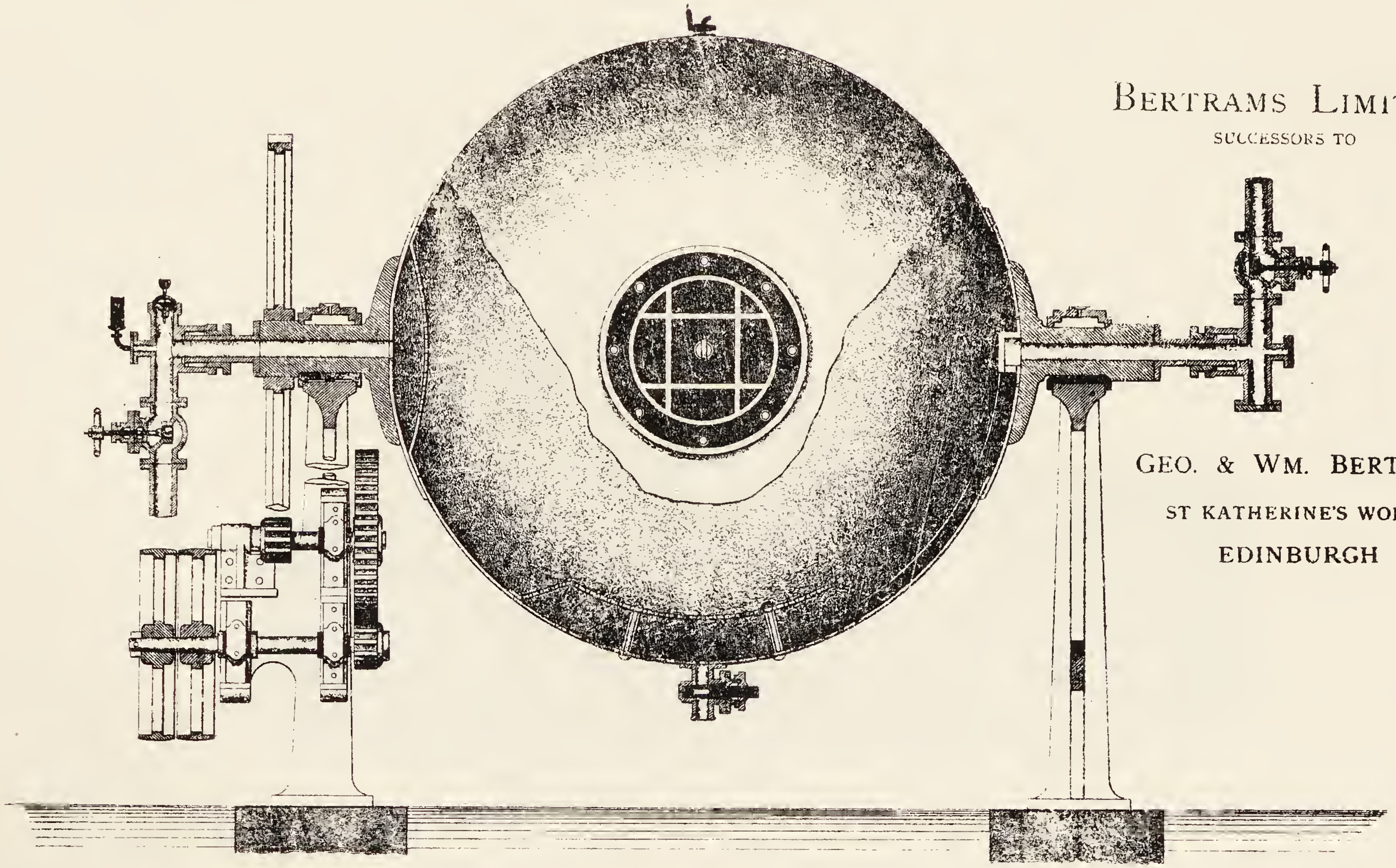
No. 4

SPHERICAL RAG BOILER



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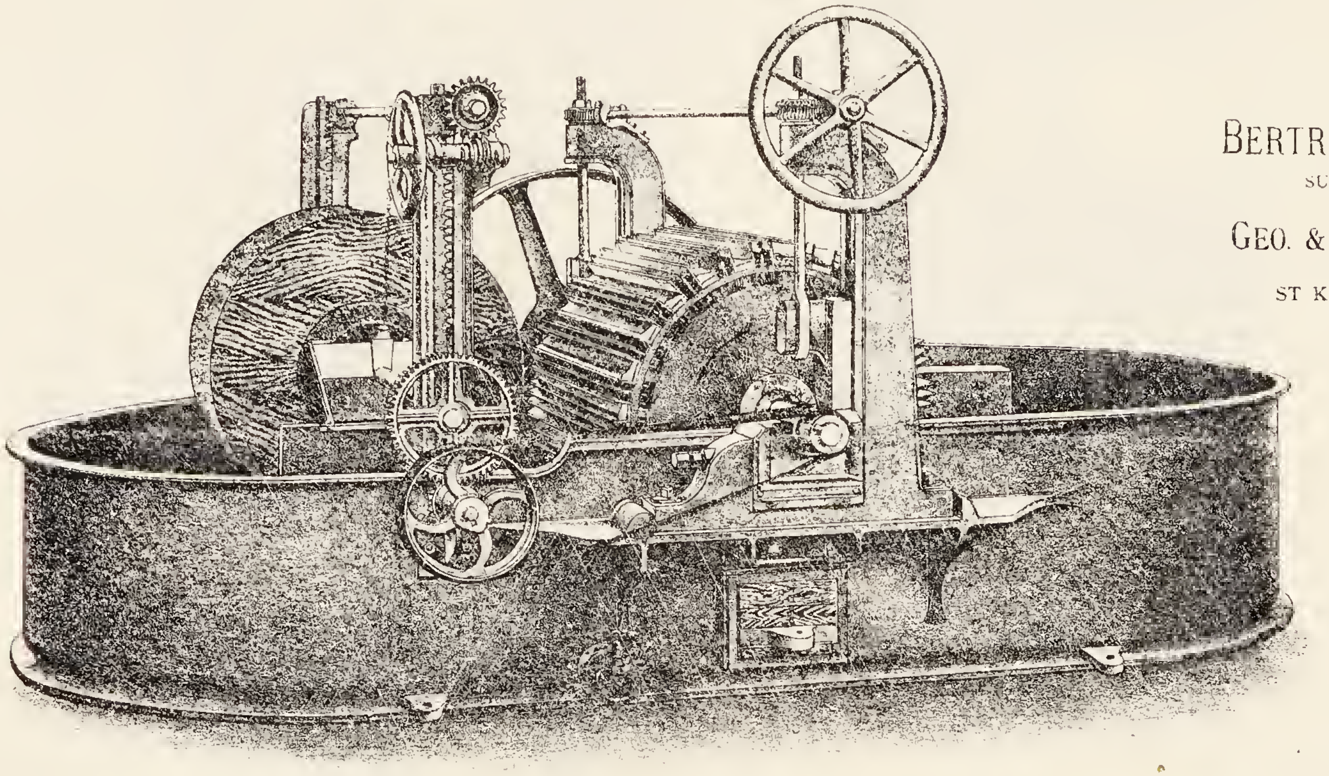
No. 5

WASHING OR BEATING ENGINE

FOR RAGS OR OTHER FIBRES

GOT UP ON THE MOST MODERN PRINCIPLES



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No. $6^{A.}$

KOLLERGANG, OR EDGE RUNNER.

FOR WORKING UP BROKE PAPER, WOOD AND STRAW PULP.

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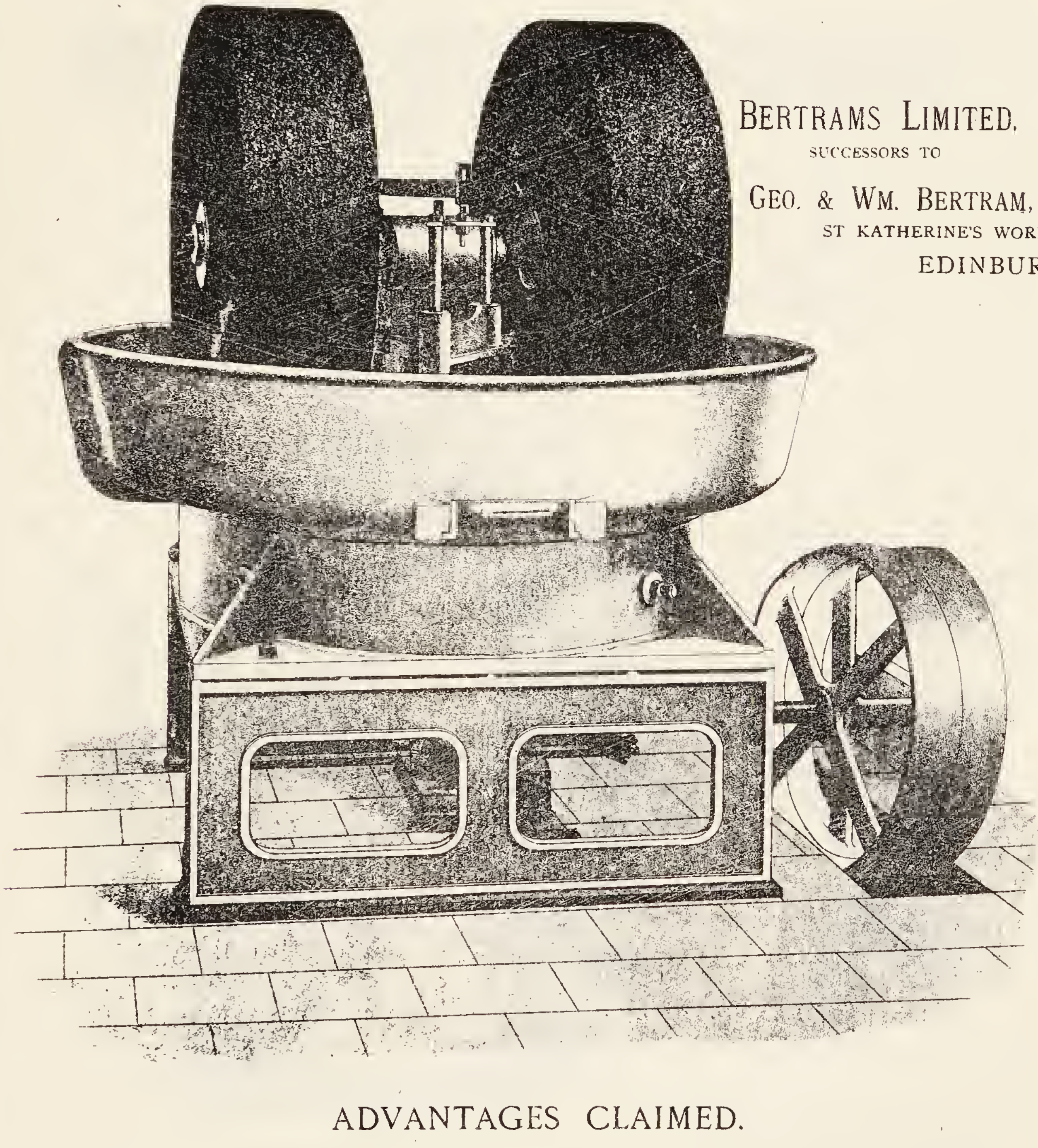
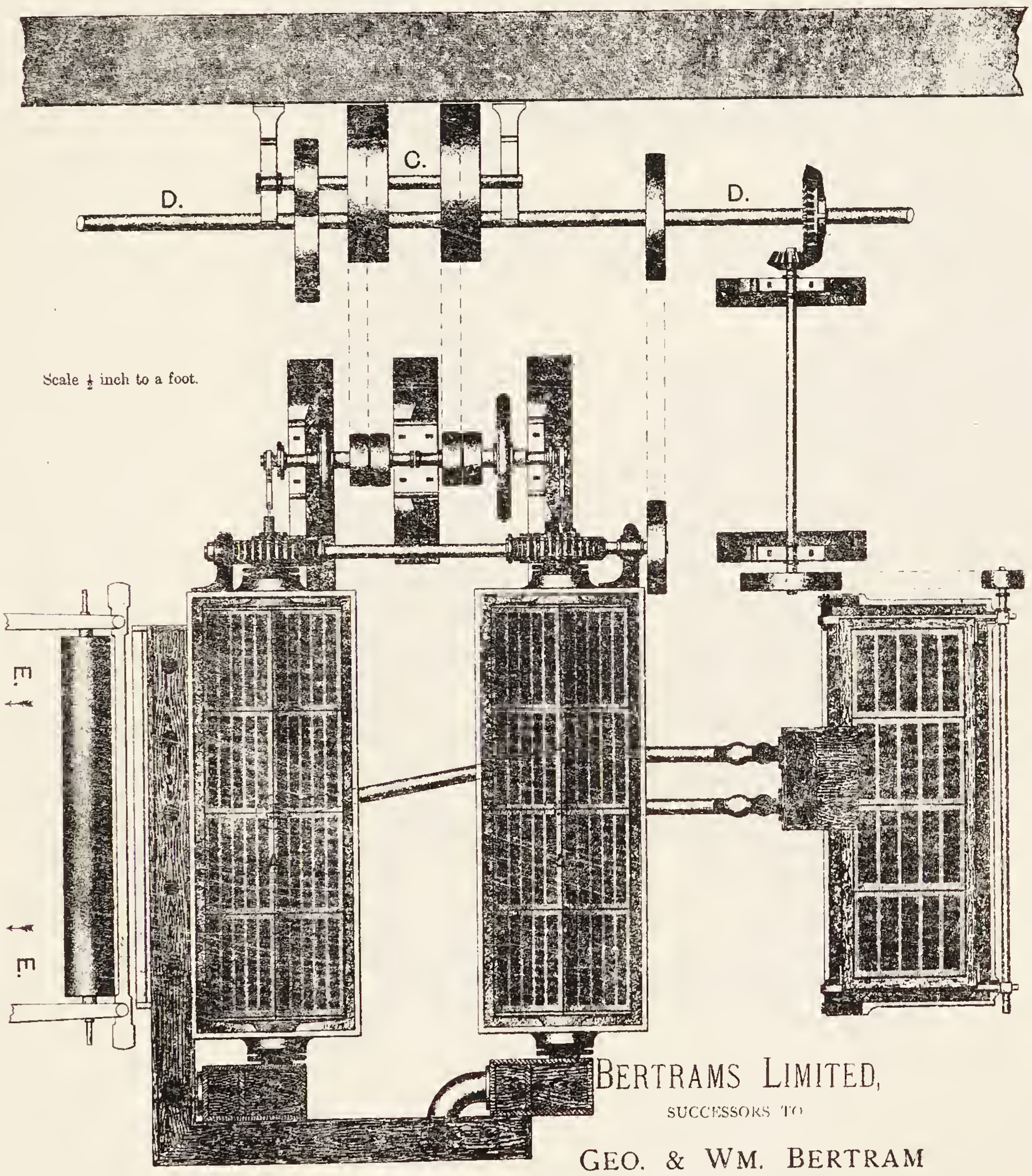


ADVANTAGES CLAIMED.

(1.) Saving of Caustic Soda.
(2.) Saving injury to Paper by Soda being retained in Broke.
(3.) Saves Loss of Fibre in the Draining Chest.
(4.) Broke better prepared.
(5.) Animal Size in Broke retained.

No. 7

PLAN OF REVOLVING STRAINERS & PATENT KNOTTER



Scale ½ inch to a foot.

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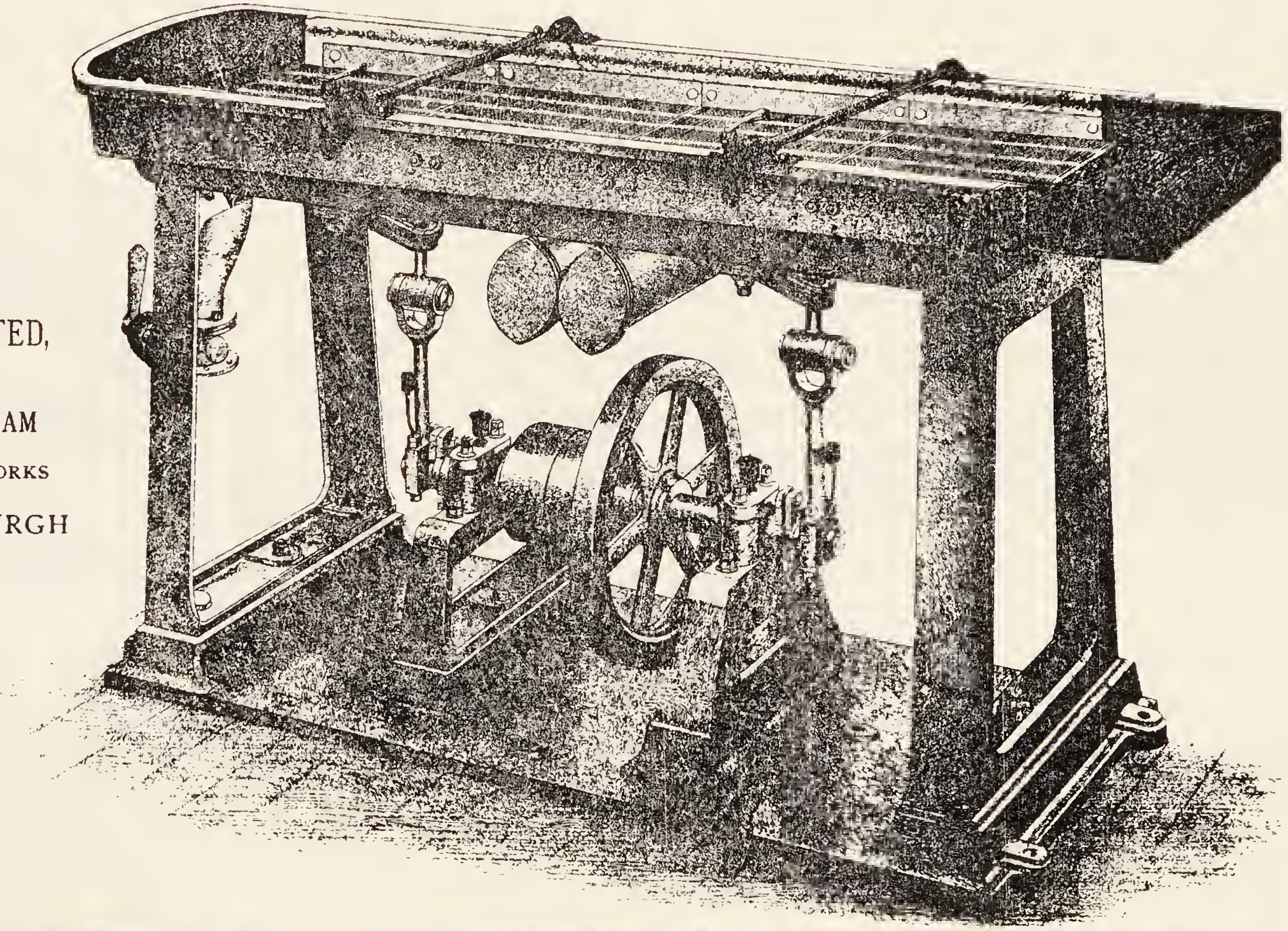
REFERENCES

A. A. *Two Revolving Strainers as applied to the Paper Machine, shewing Gearing for Strainers and Bellows.*
B. *Patent Knotter as used for two Strainers.*
C. *Counter Shaft overhead.*
D. D. *Back Shaft of Machine.*
E. E. *Wire of Paper Machine.*

No. 8

PATENT FLAT SELF-CLEANSING STRAINER

WHICH WORKS PERFECTLY NOISELESS; WILL PASS FROM 18 TO 20 TONS OF FINEST PAPER PER WEEK
THE MOST MODERN AND EFFICIENT IN USE



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No. 9

CONICAL PULP SAVER

WHICH REQUIRES NO ATTENTION, AND IS A GREAT SAVING TO PAPER MILLS

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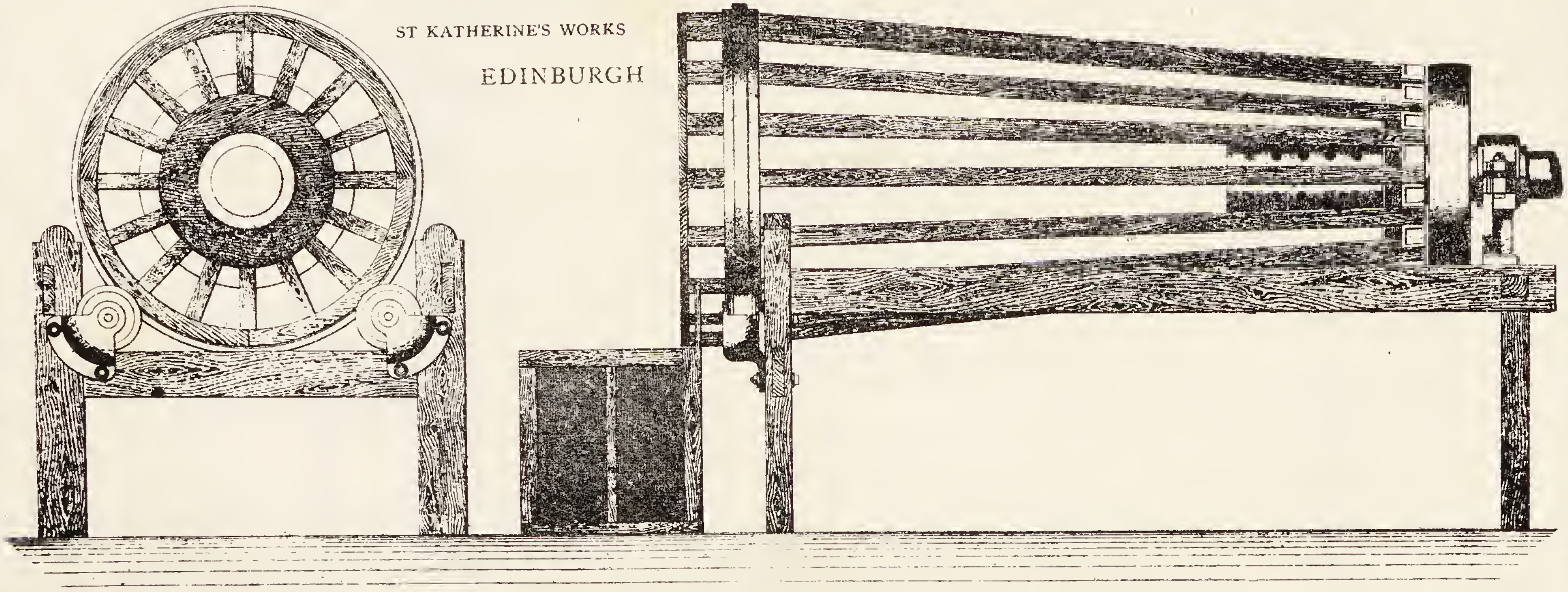

No. 10

ELEVATION OF PAPER-MAKING MACHINE

FOR

FINE PRINTINGS AND WRITINGS

BERTRAMS LIMITED,
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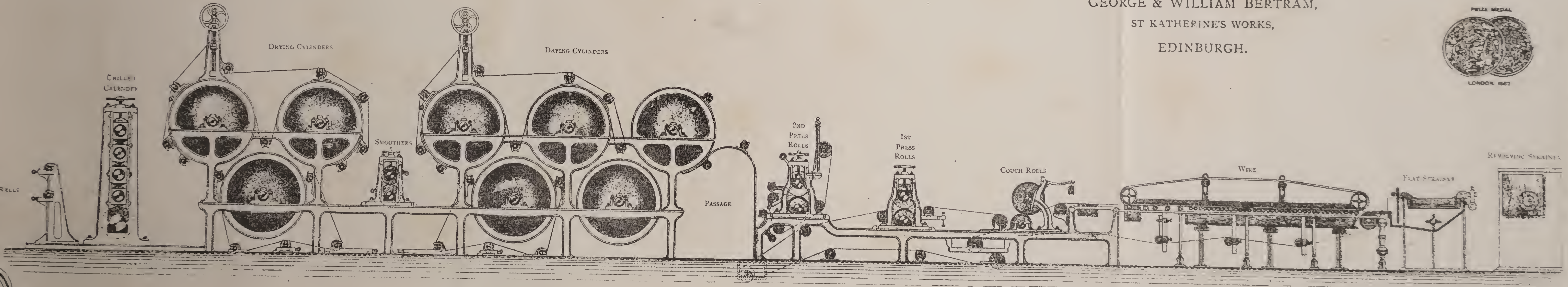
ST KATHERINE'S WORKS,
EDINBURGH.

PRIZE MEDAL
LONDON 1862



No. 11

ELEVATION OF PAPER-MAKING MACHINE

FOR

FINE PRINTINGS AND WRITINGS

PRIZE MEDAL
LONDON, 1862

BERTRAMS LIMITED,
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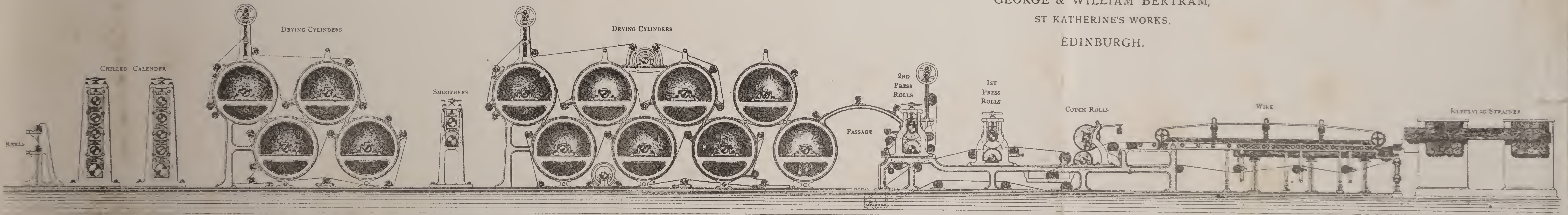
ST KATHERINE'S WORKS,
EDINBURGH.



No. 12

ELEVATION OF PAPER-MAKING MACHINE

FOR

FINE PRINTINGS AND WRITINGS

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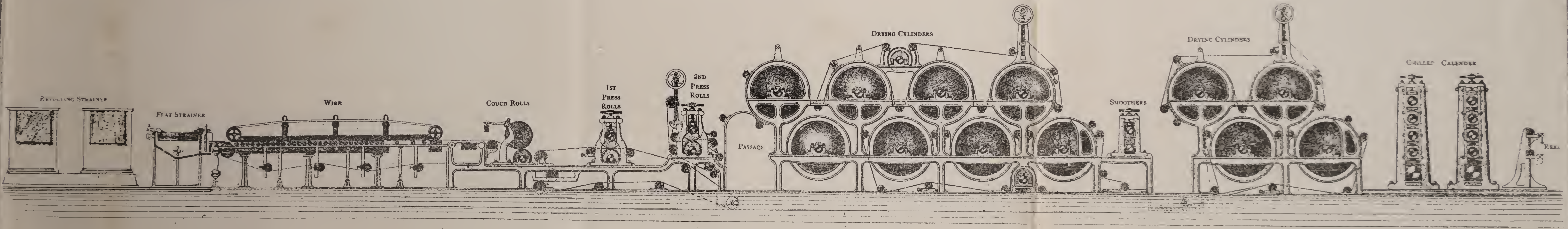
ST KATHERINE'S WORKS,
EDINBURGH.



No. 13

YANKEE MACHINE

BERTRAMS LIMITED,
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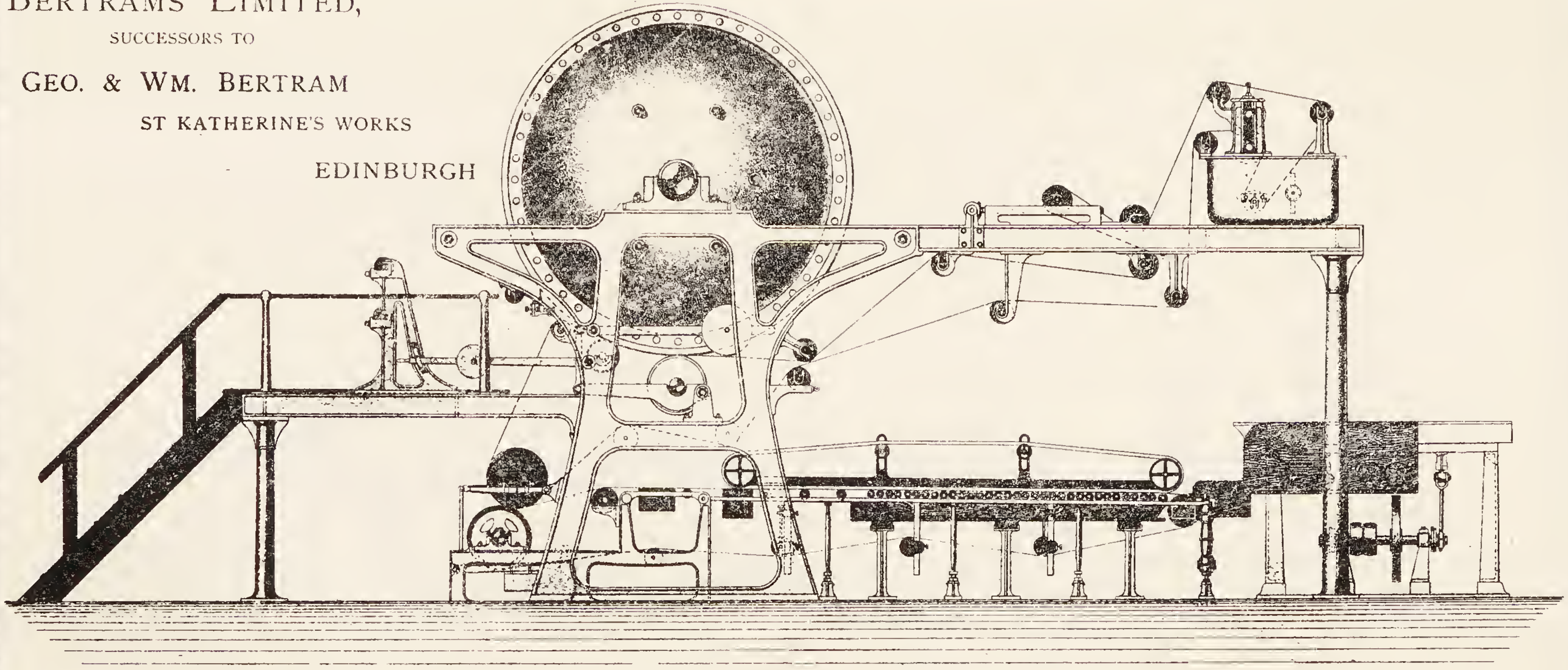

No. 13^{A}

ELEVATION OF IMPROVED WET END
FOR PAPER MACHINES
WITH PATENT FLAT STRAINERS APPLIED

BERTRAMS LIMITED,
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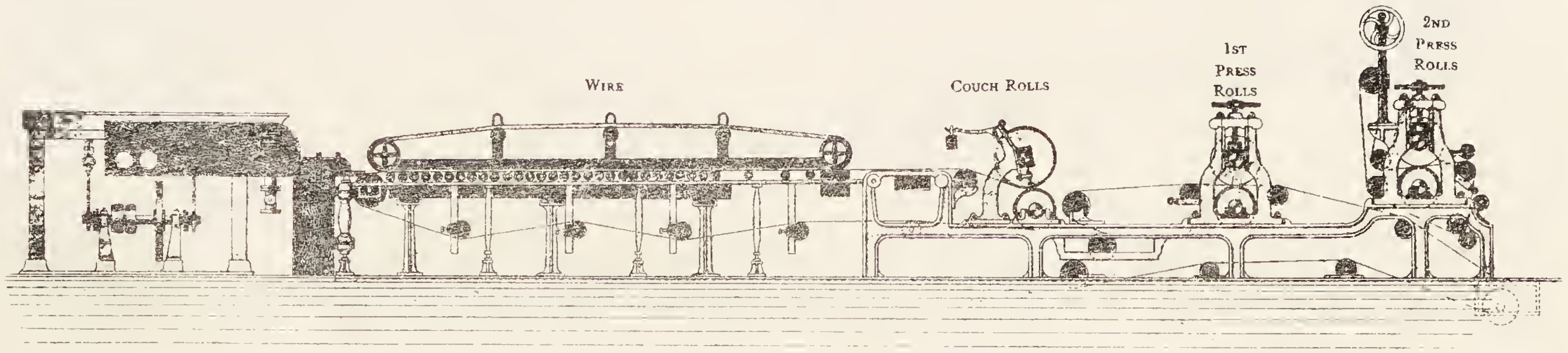


No. 13^A (Second Sheet)

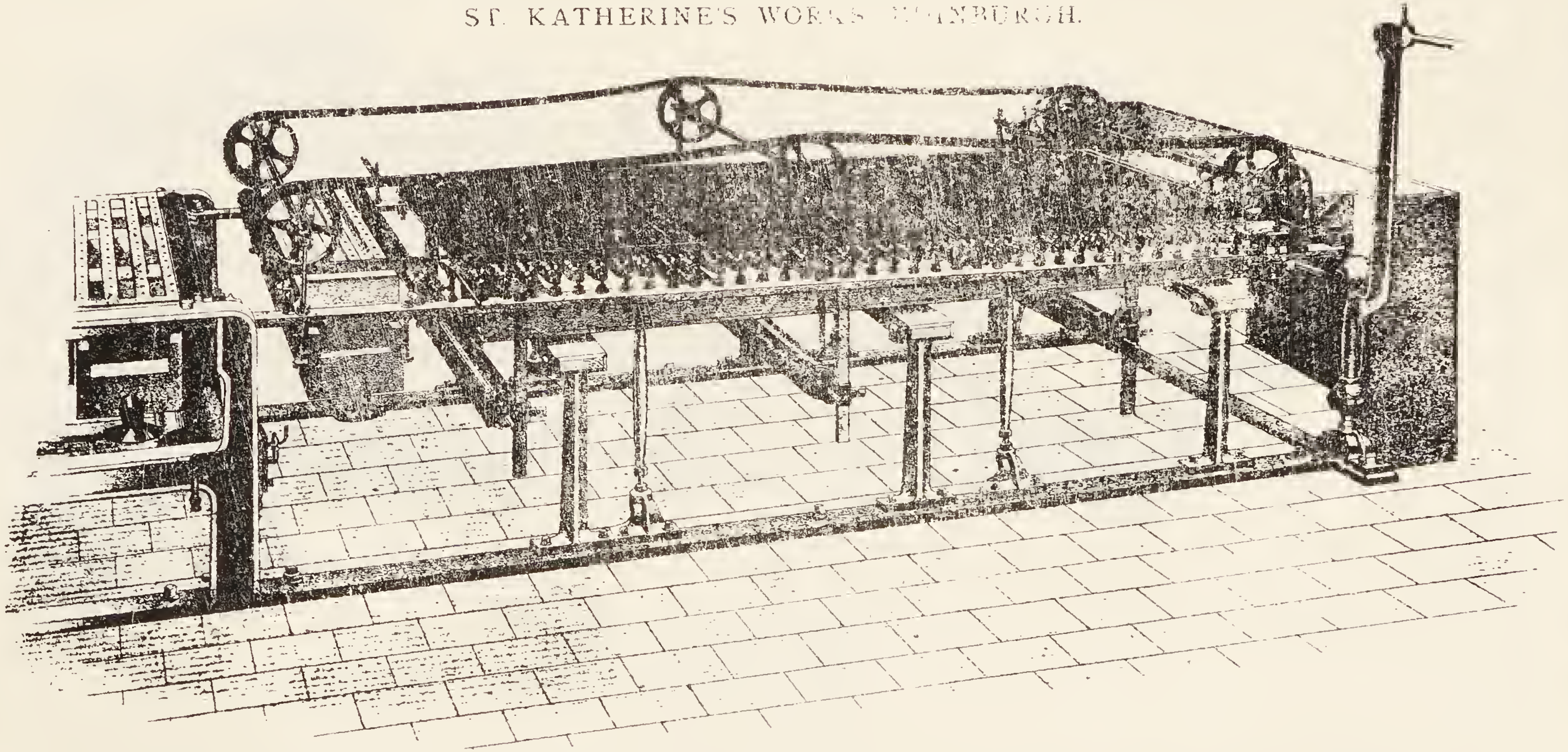
ARCHIBALD & PURDIE'S

PATENT DECKLE

(MOST ECONOMICAL AND EFFICIENT DECKLE IN USE.)

Sole Manufacturers–BERTRAMS LIMITED,

ST. KATHERINE'S WORKS, EDINBURGH.



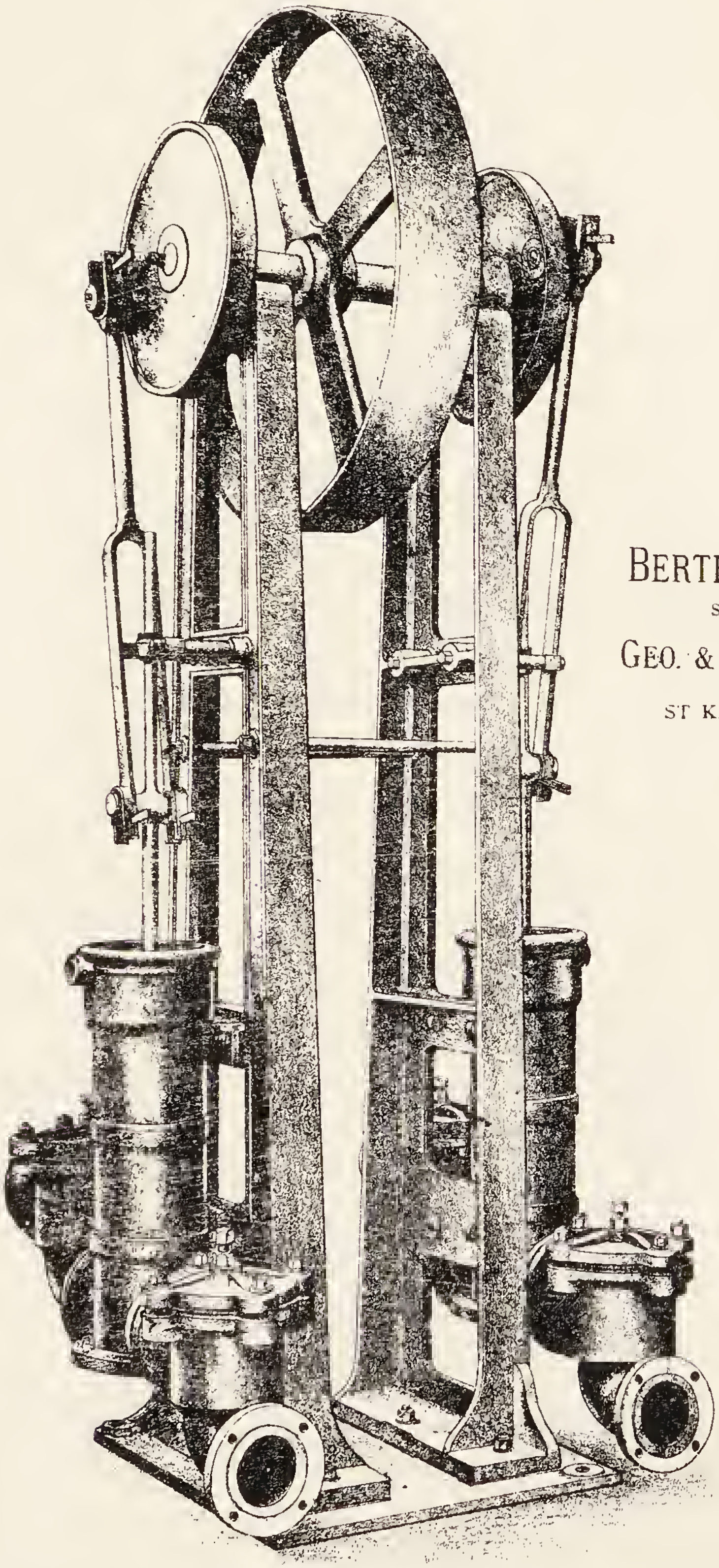
This Deckle, of which we are the sole makers, has been duly acknowledged by the Trade to be of great importance, proving beyond doubt that a better edge can be made with this apparatus. It is of the simplest description and can be shifted without stopping or interfering with Paper Machine. Long apron can be worked, and Deckle need not be removed when changing wire. Waviness obviated

SEE LIST OF USERS ON BACK.

No. 14

BACK WATER PUMPS

FOR PUMPING SIZE WATER, &c.



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No. 14^{A}

STUFF AND BACK WATER PUMPS

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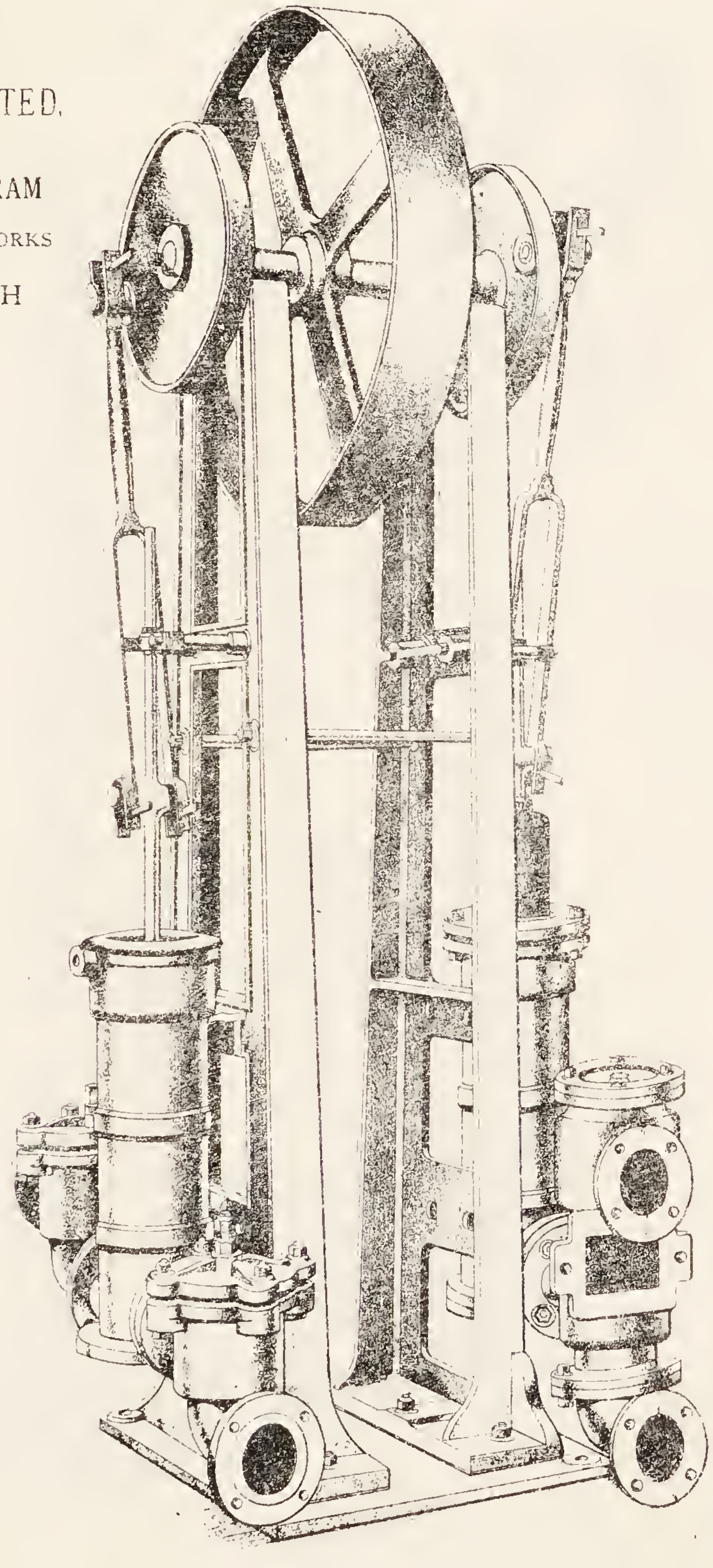
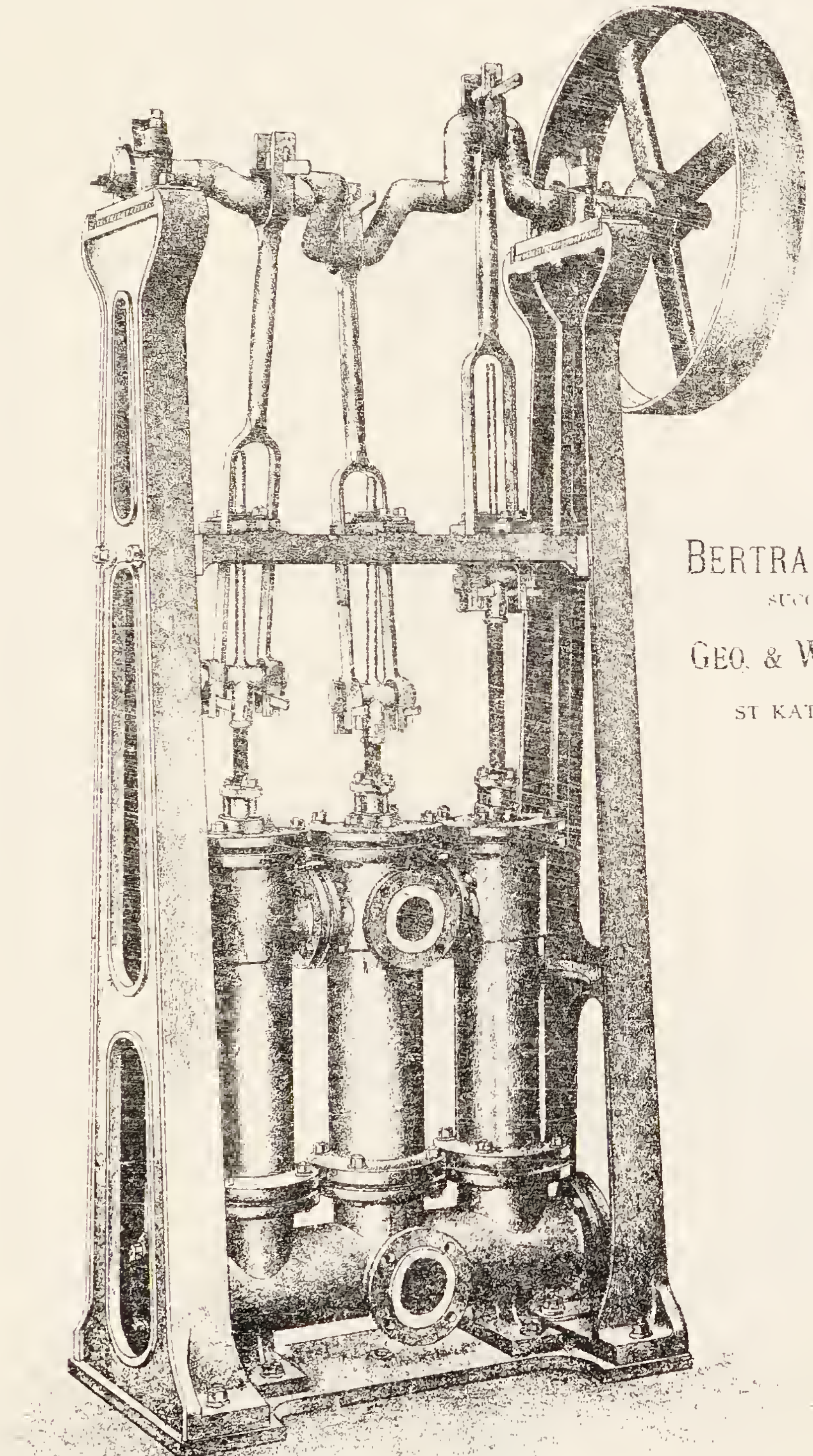


No. 15

VACUUM PUMPS

THREE BARRELS, AND MANY IMPROVEMENTS ON DETAILS



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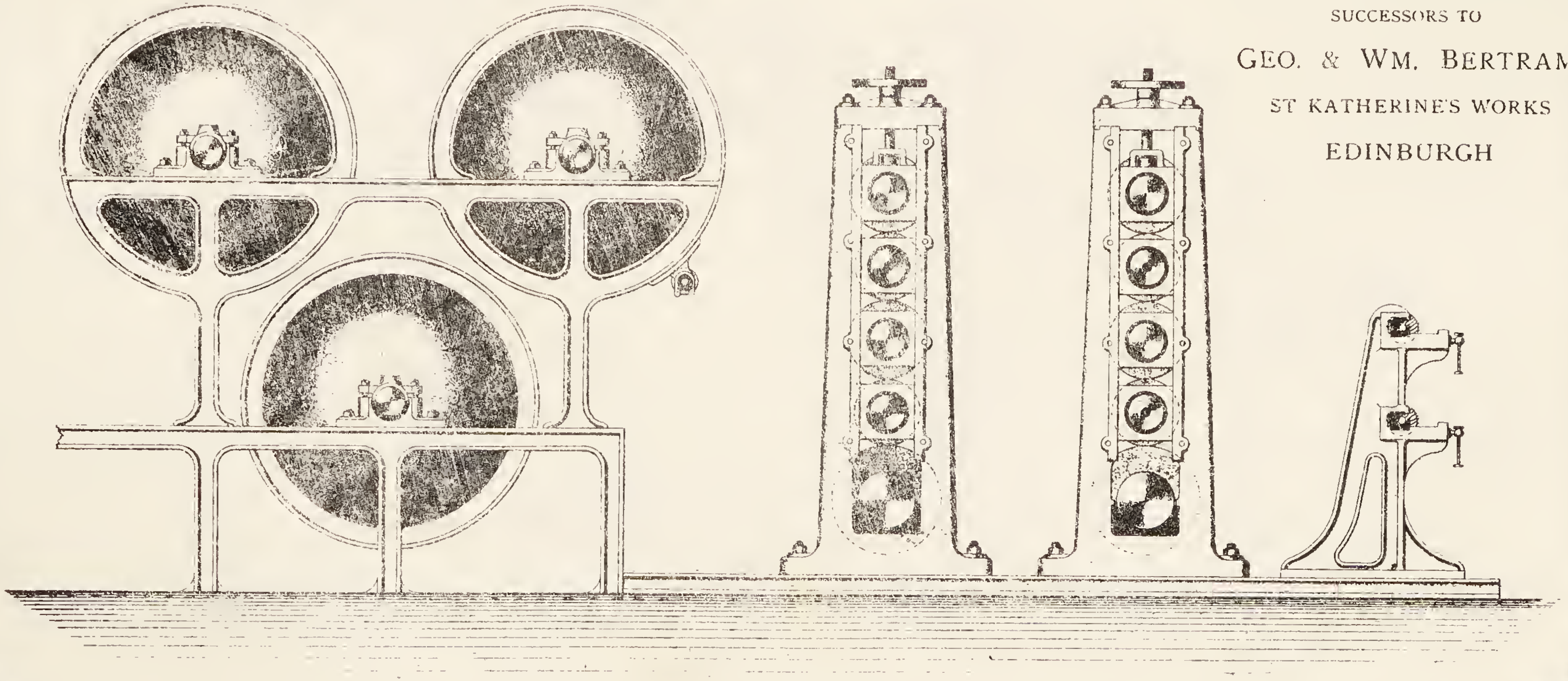
No 16

CHILLED CALENDER ROLLS

SCOTCH MAKE, NOW LARGELY ADOPTED, AND GUARANTEED TO BE HARDER THAN THOSE OF AMERICAN MANUFACTURE



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No. 17

OUR WELL-KNOWN

REVOLVING KNIFE CUTTING MACHINE

HUNDREDS OF WHICH ARE IN USE

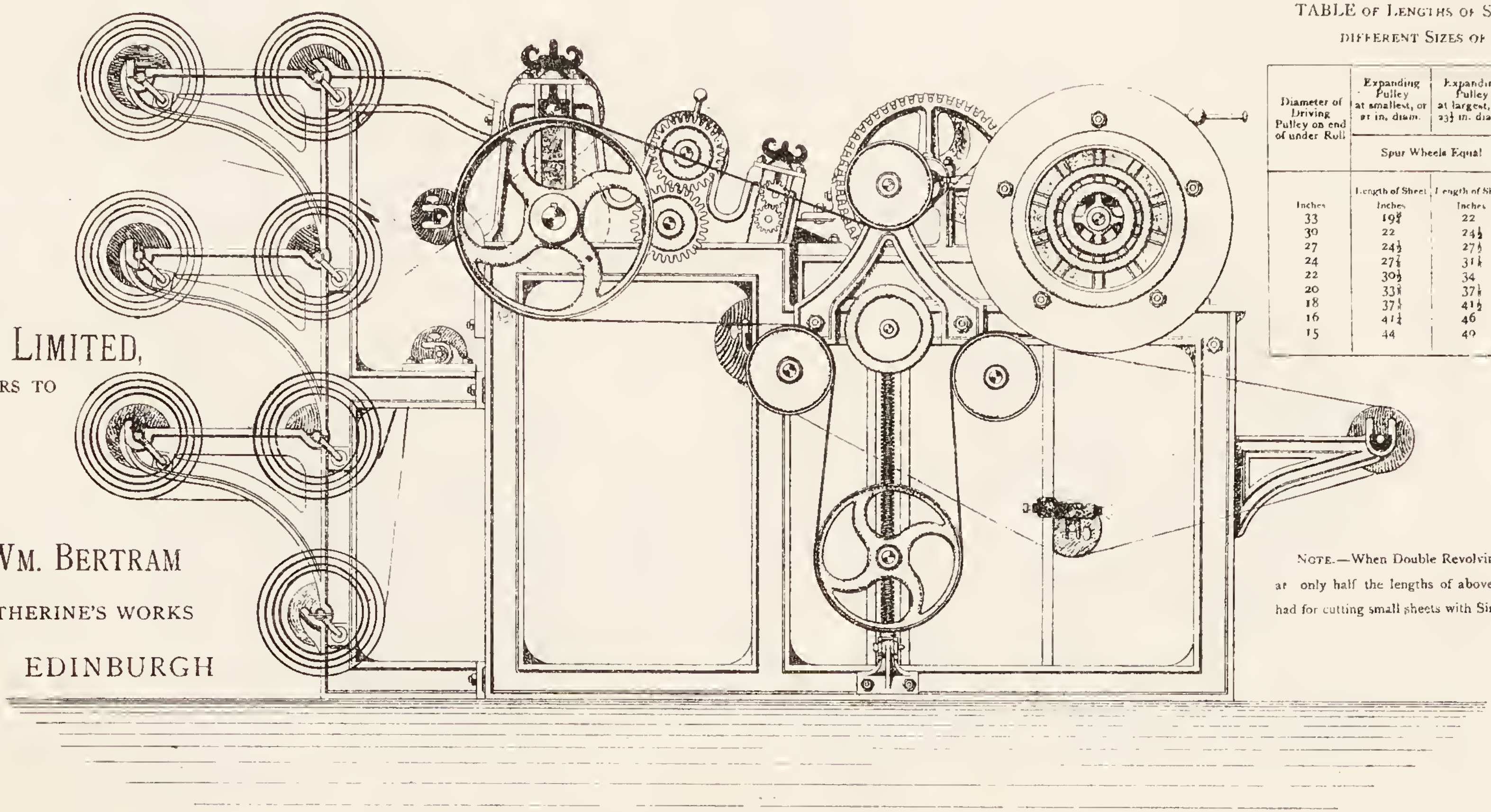

TABLE OF LENGTHS OF SHEETS CUT, AND THE DIFFERENT SIZES OF PULLEYS USED.

Diameter of Driving Pulley on end of under Roll	Expanding Pulley at smallest, or 21 in. diam.	Expanding Pulley at largest, or 23½ in. diam	Expanding Pulley at smallest	Expanding Pulley at largest
	Spur Wheels Equal		Spur Wheels 2 to 1	
	Length of Sheet	Length of Sheet	Length of Sheet	Length of Sheet
Inches	Inches	Inches	Inches	Inches
33	19¾	22	39½	44
30	22	24½	44	49
27	24½	27½	48½	55
24	27⅞	31⅛	55¾	62¼
22	30½	34	61	68
20	33⅜	37⅛	66¾	74¼
18	37⅛	41½	74¼	83
16	41¼	46	82½	92
15	44	49	88	98

NOTE.—When Double Revolving Knife is used, the sheets are only half the lengths of above. Special Pulleys can be had for cutting small sheets with Single Knife.

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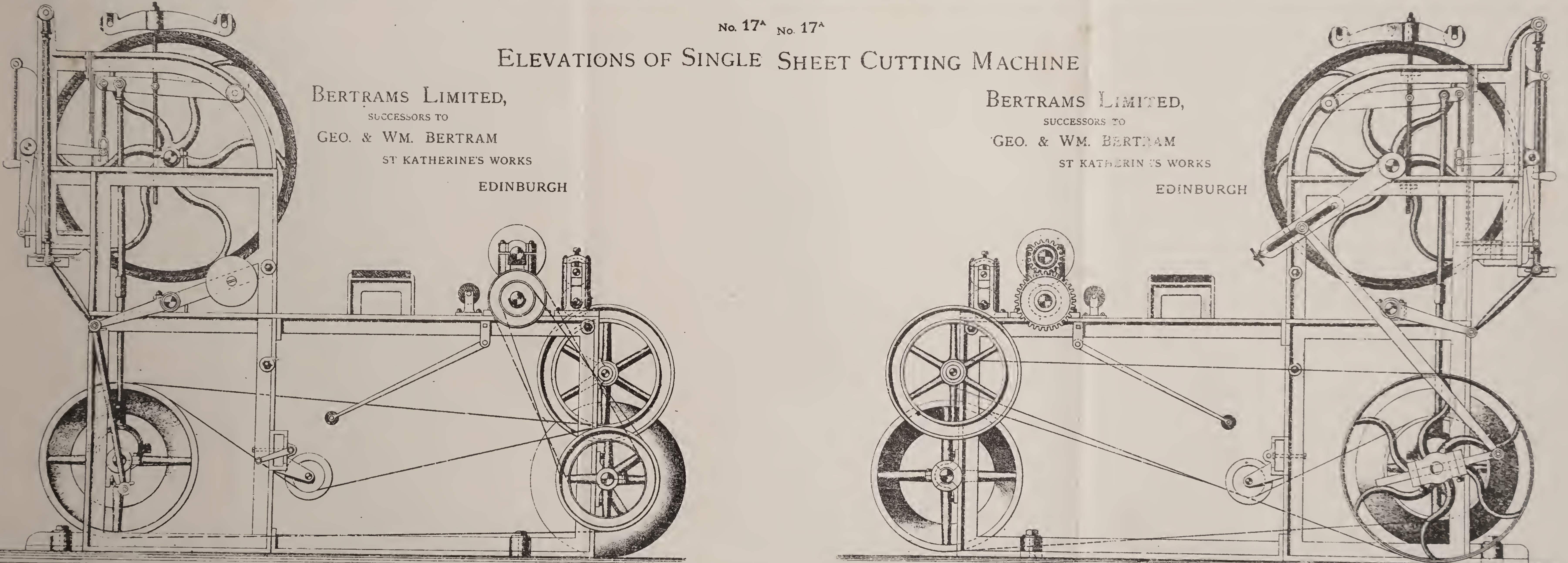
No. 17^{A} No. 17^{A}

ELEVATIONS OF SINGLE SHEET CUTTING MACHINE



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No. 18

BOARDING CALENDER

OF THE VERY HEAVIEST DESCRIPTION. MADE EITHER WITH LEVERS OR HAND WHEELS FOR APPLYING PRESSURE

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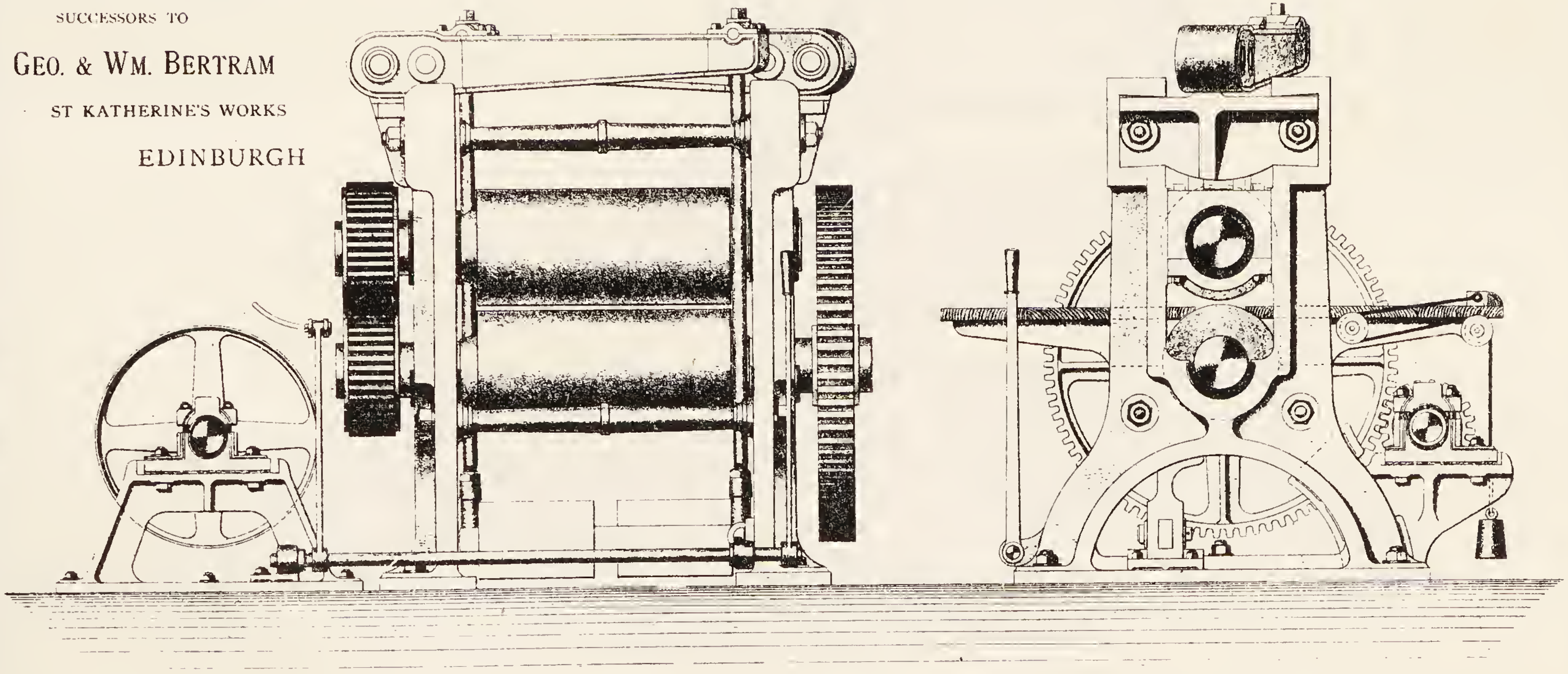
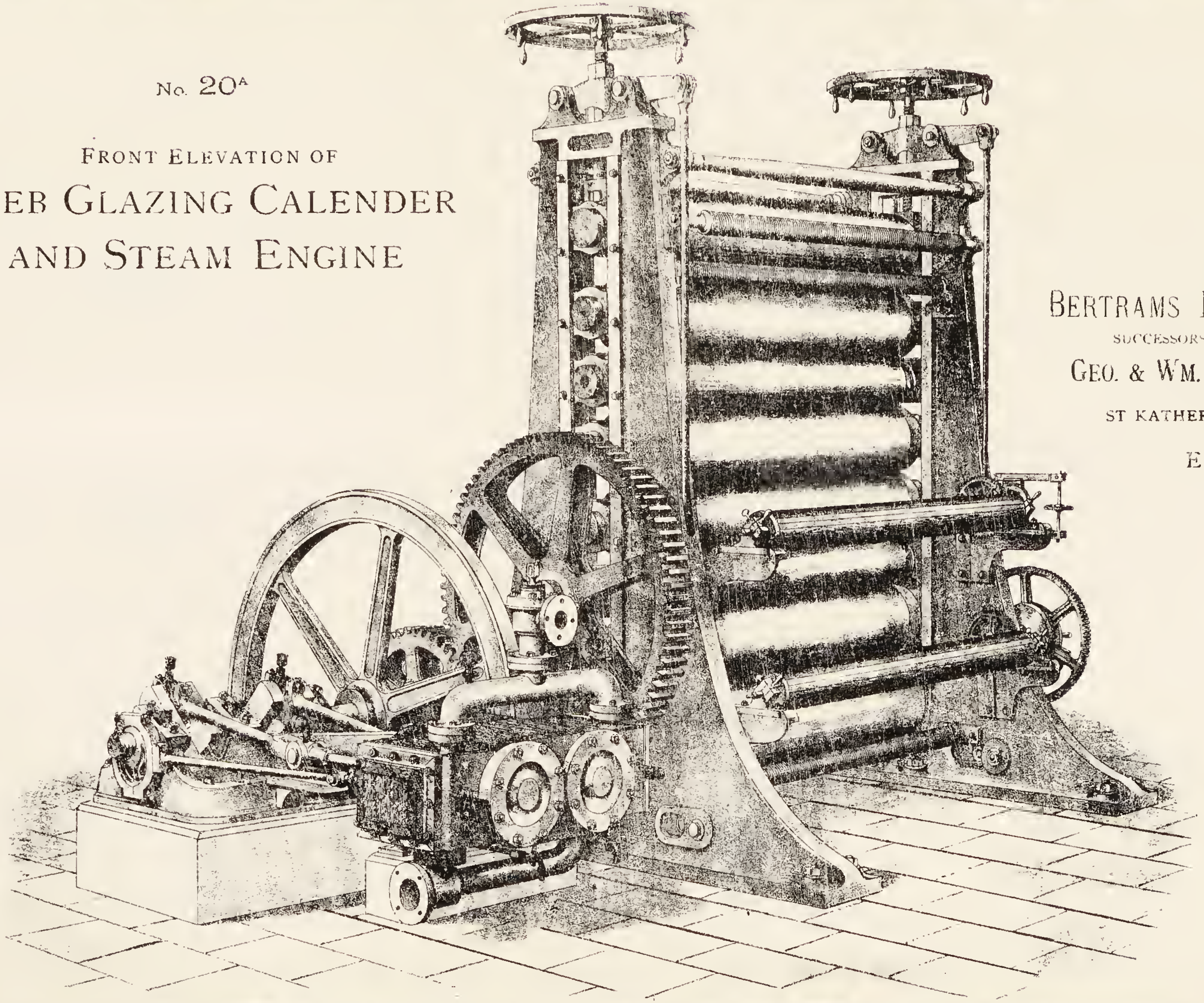


No. 20^{A}

FRONT ELEVATION OF

WEB GLAZING CALENDER AND STEAM ENGINE



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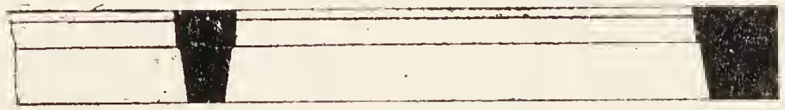
EDINBURGH

No. 24

SECTIONS OF STRAINER PLATES (FULL SIZE)

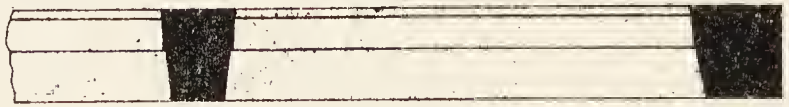
OF THE BEST WORKMANSHIP AND FINISH. QUALITY GUARANTEED

B FLAT



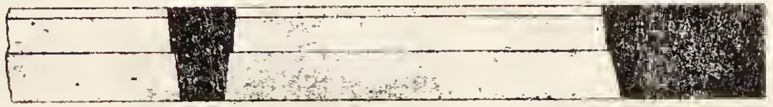
3d. Per Superficial Inch

B^2/FLAT



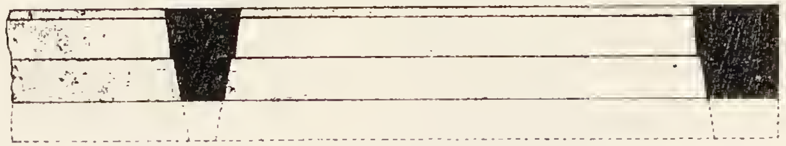
3½d. Per Superficial Inch

B^2/REVOLVING



3½d. Per Superficial Inch

C FLAT, AND REVOLVING



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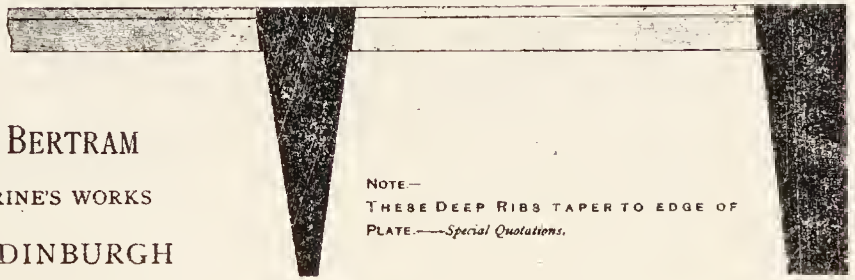

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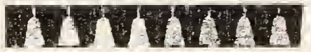

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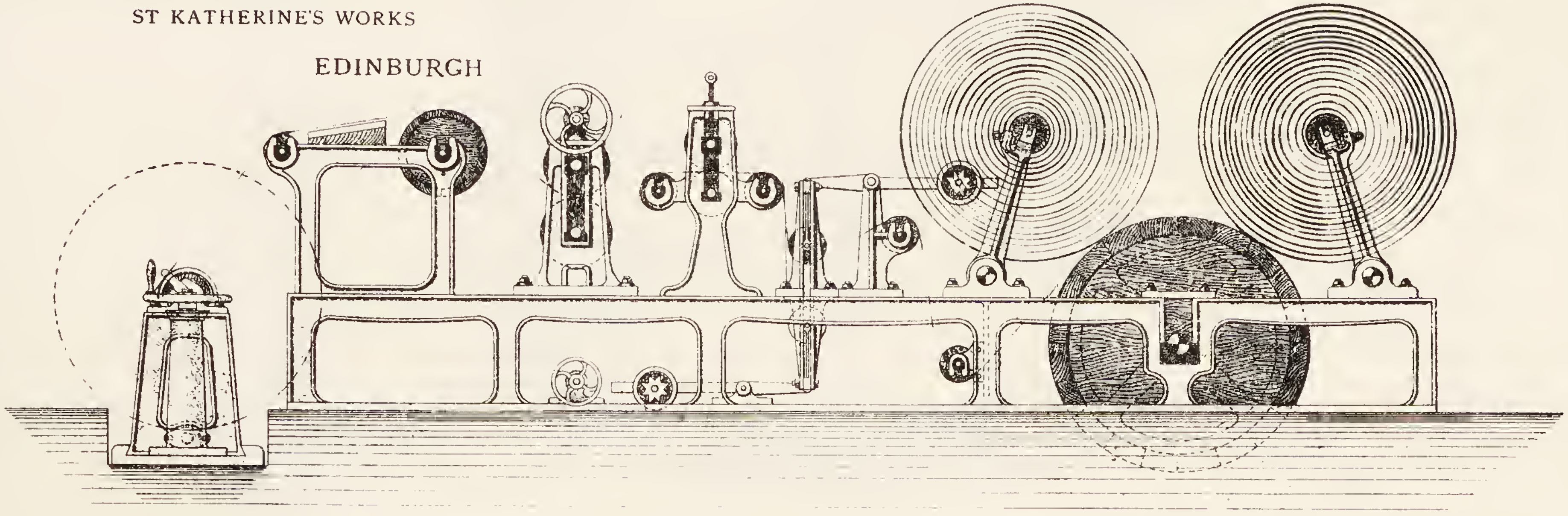

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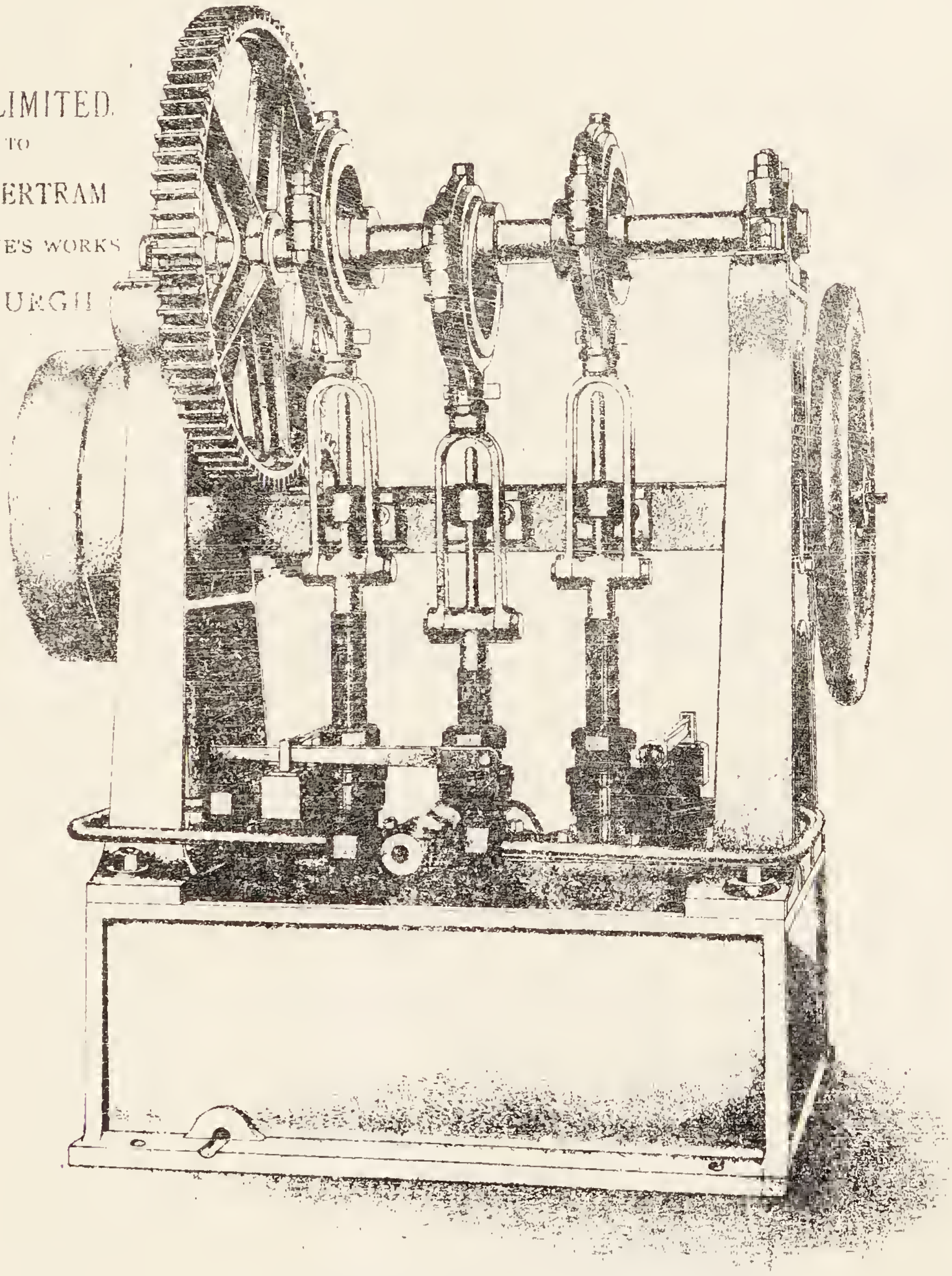

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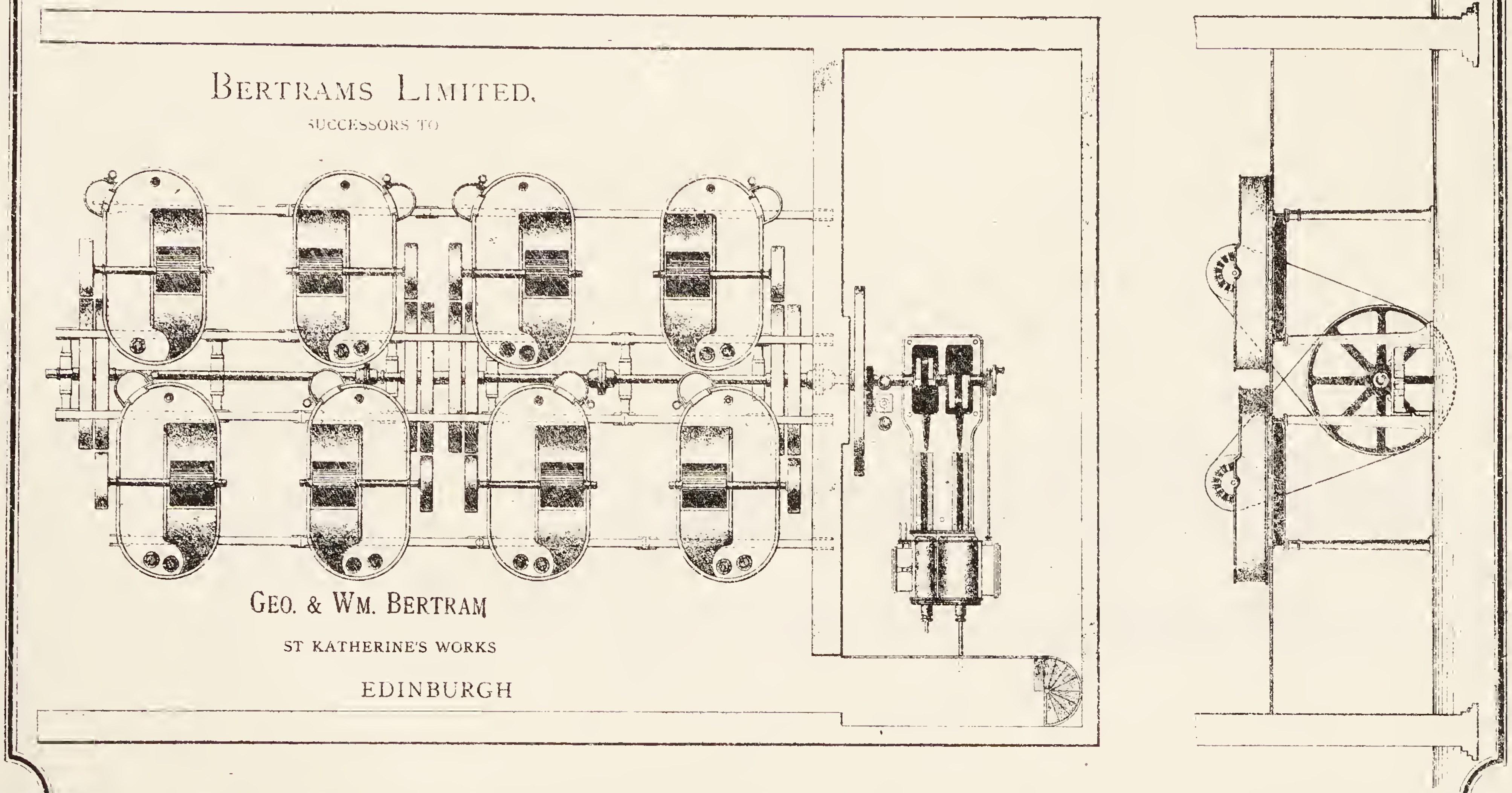

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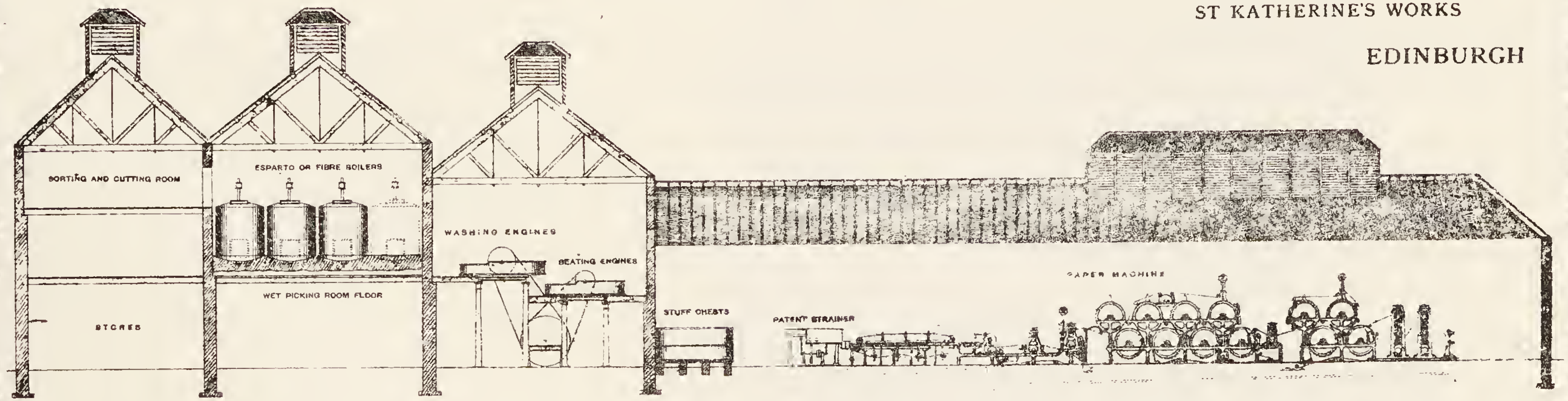

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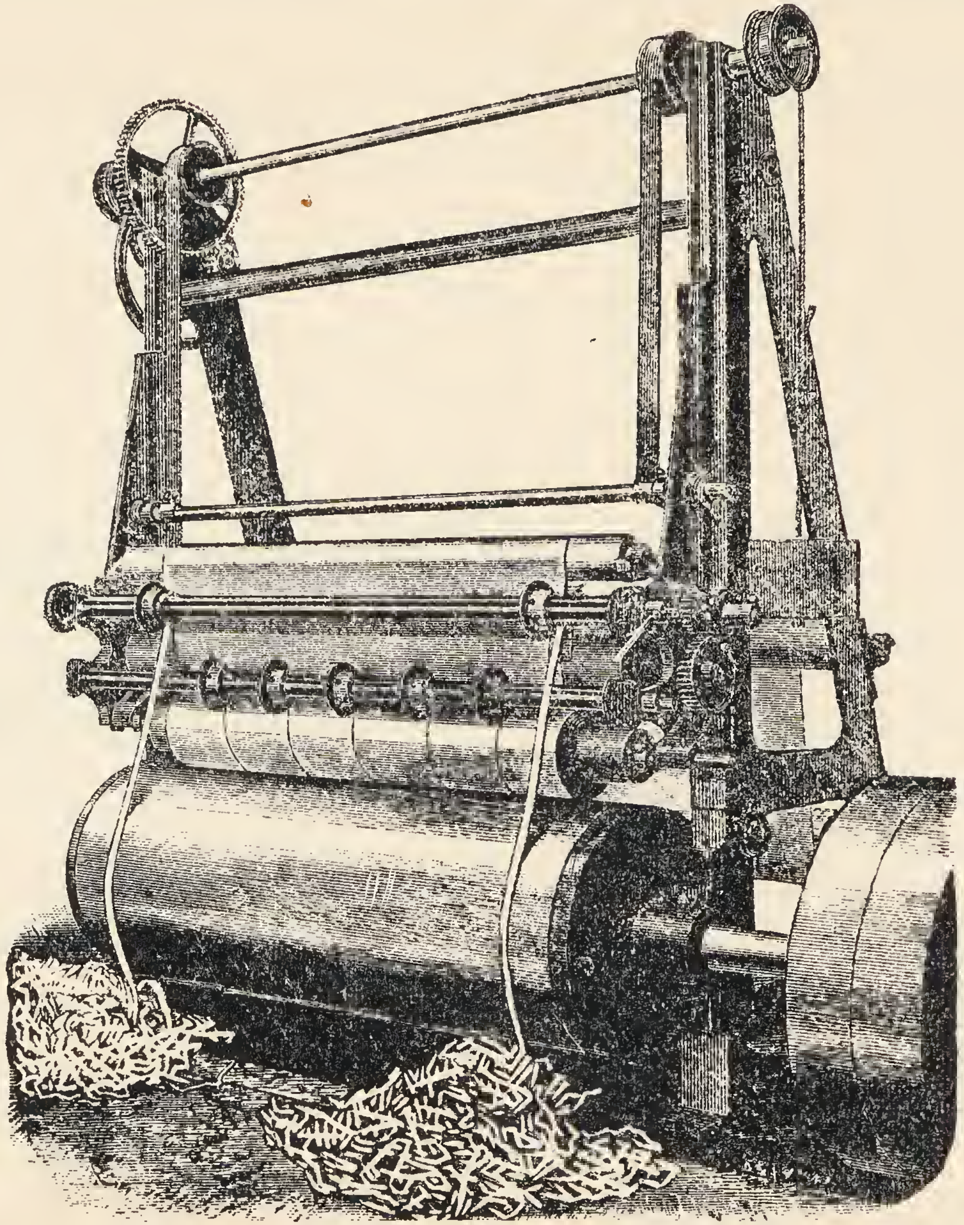

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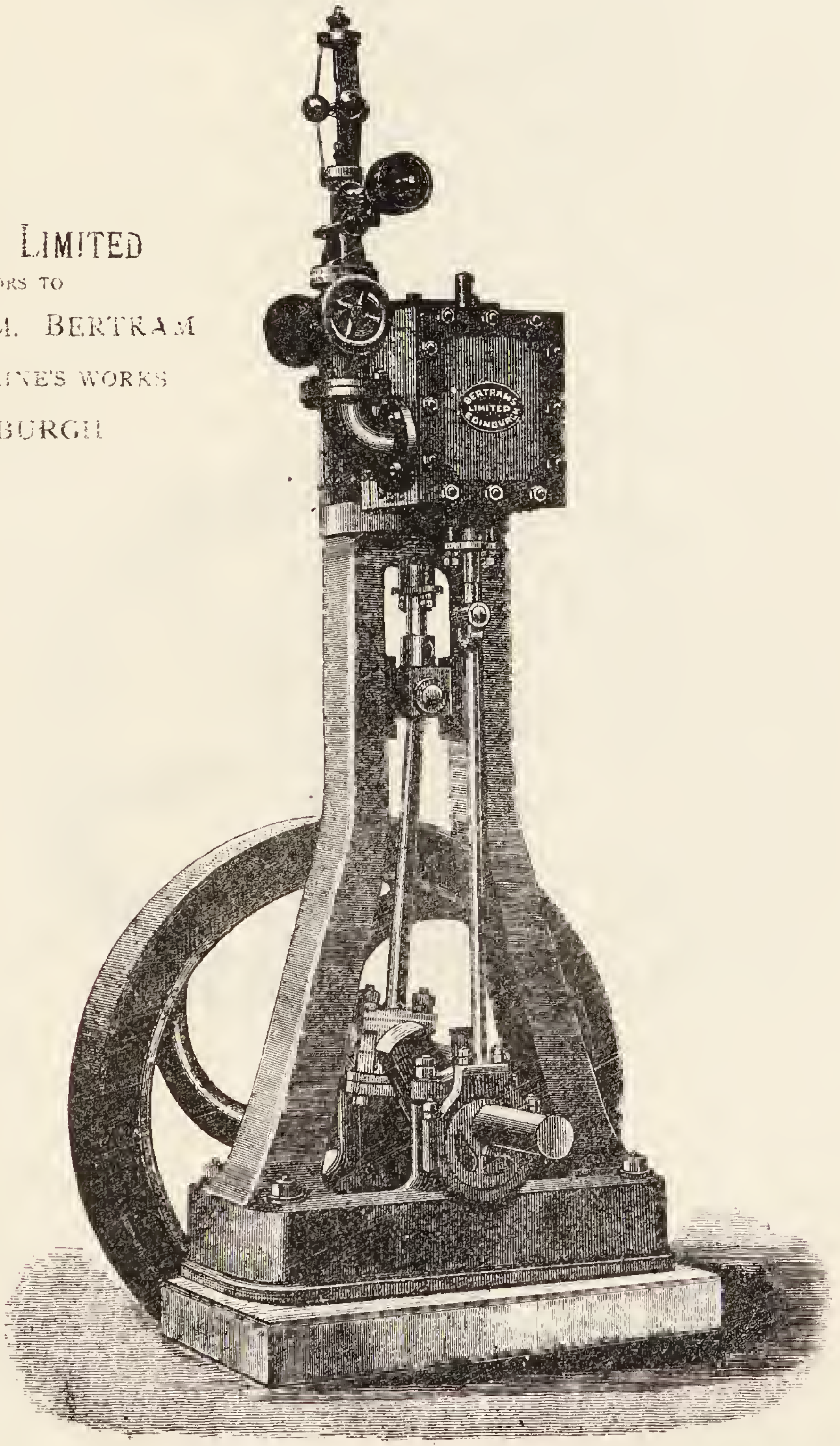

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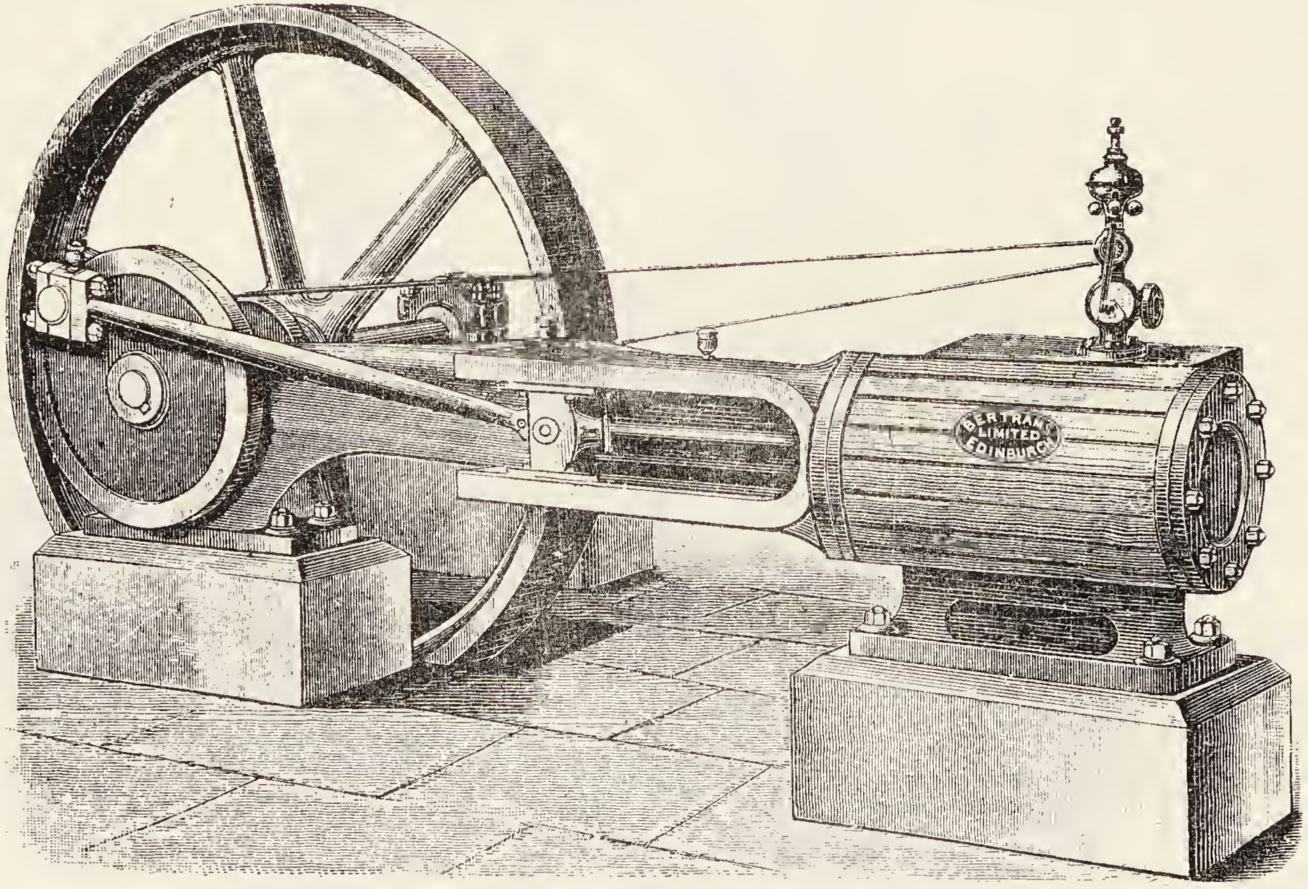

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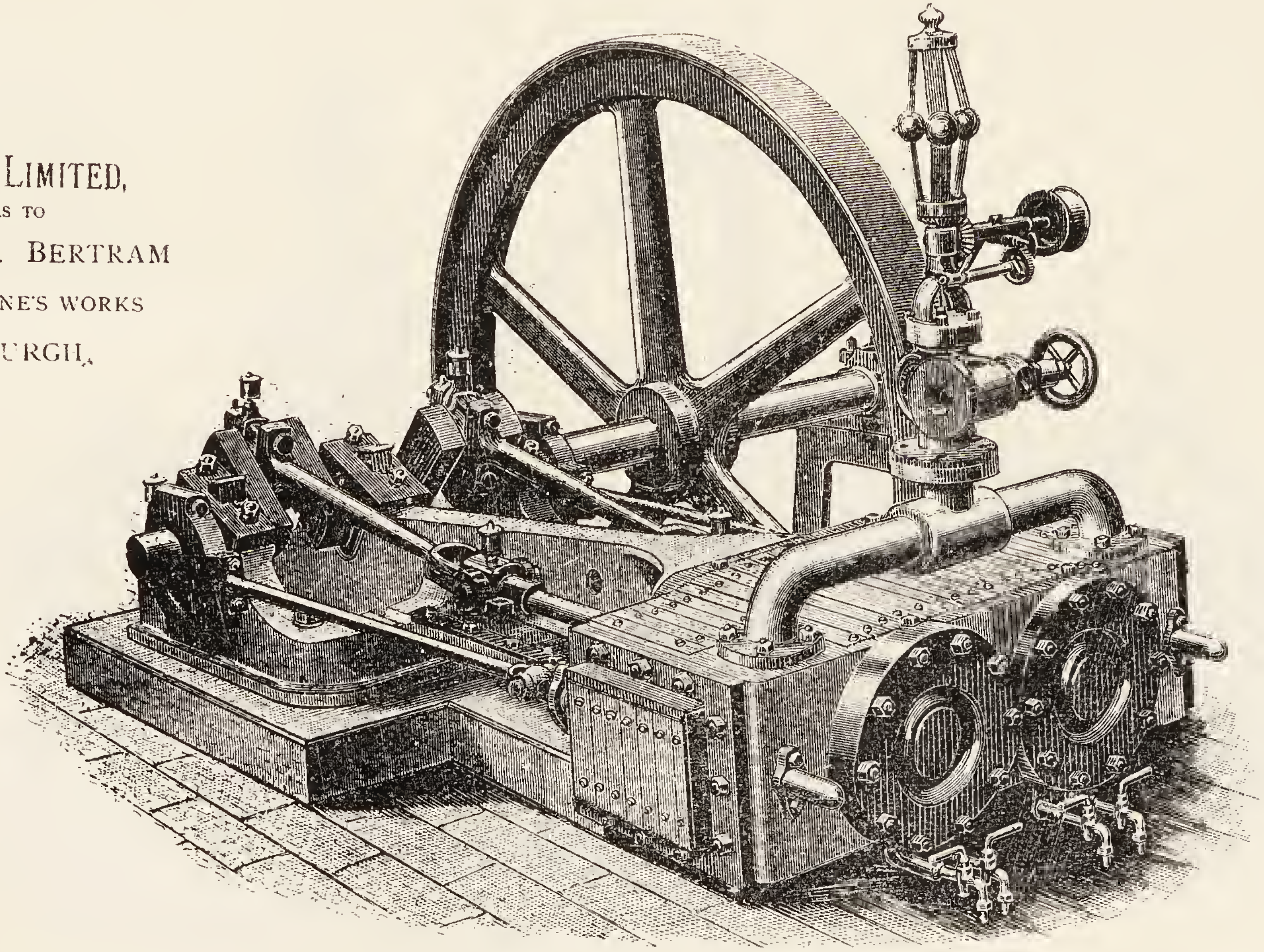

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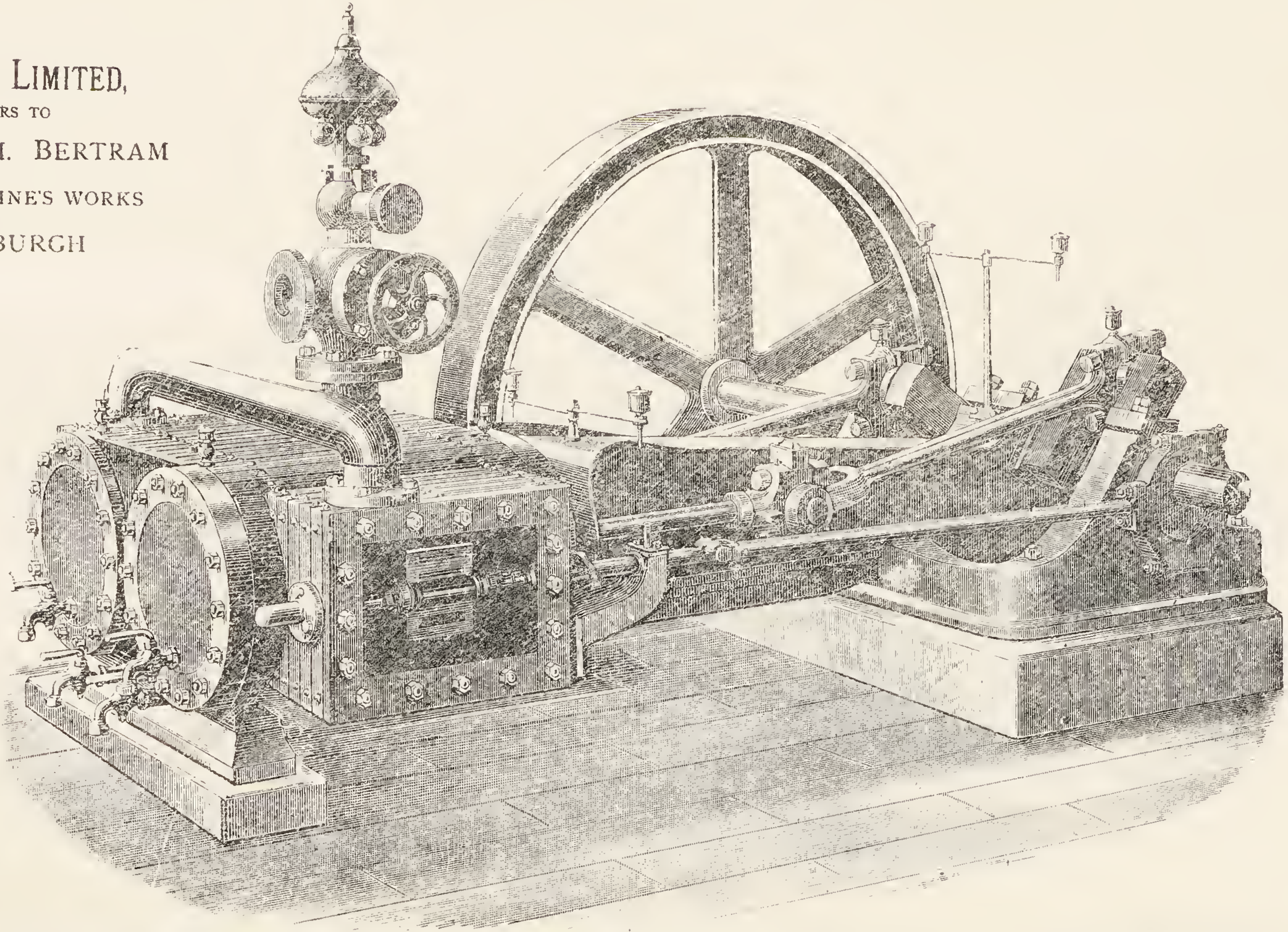

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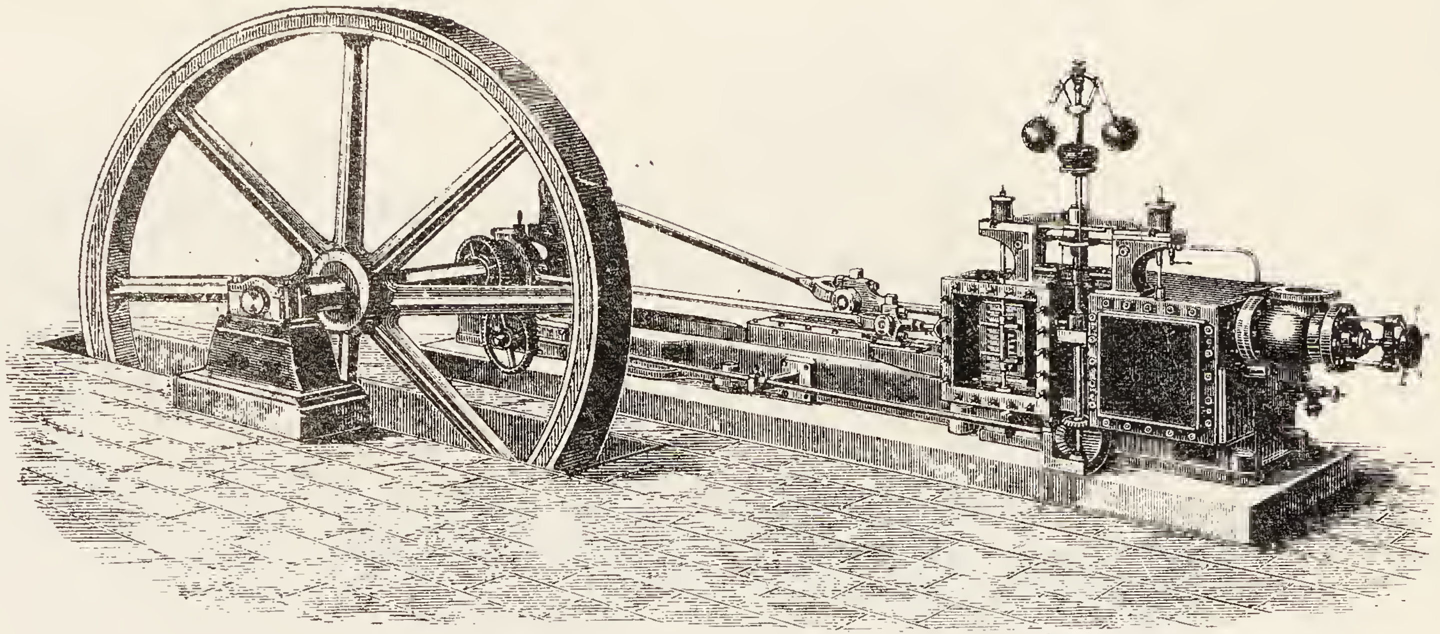

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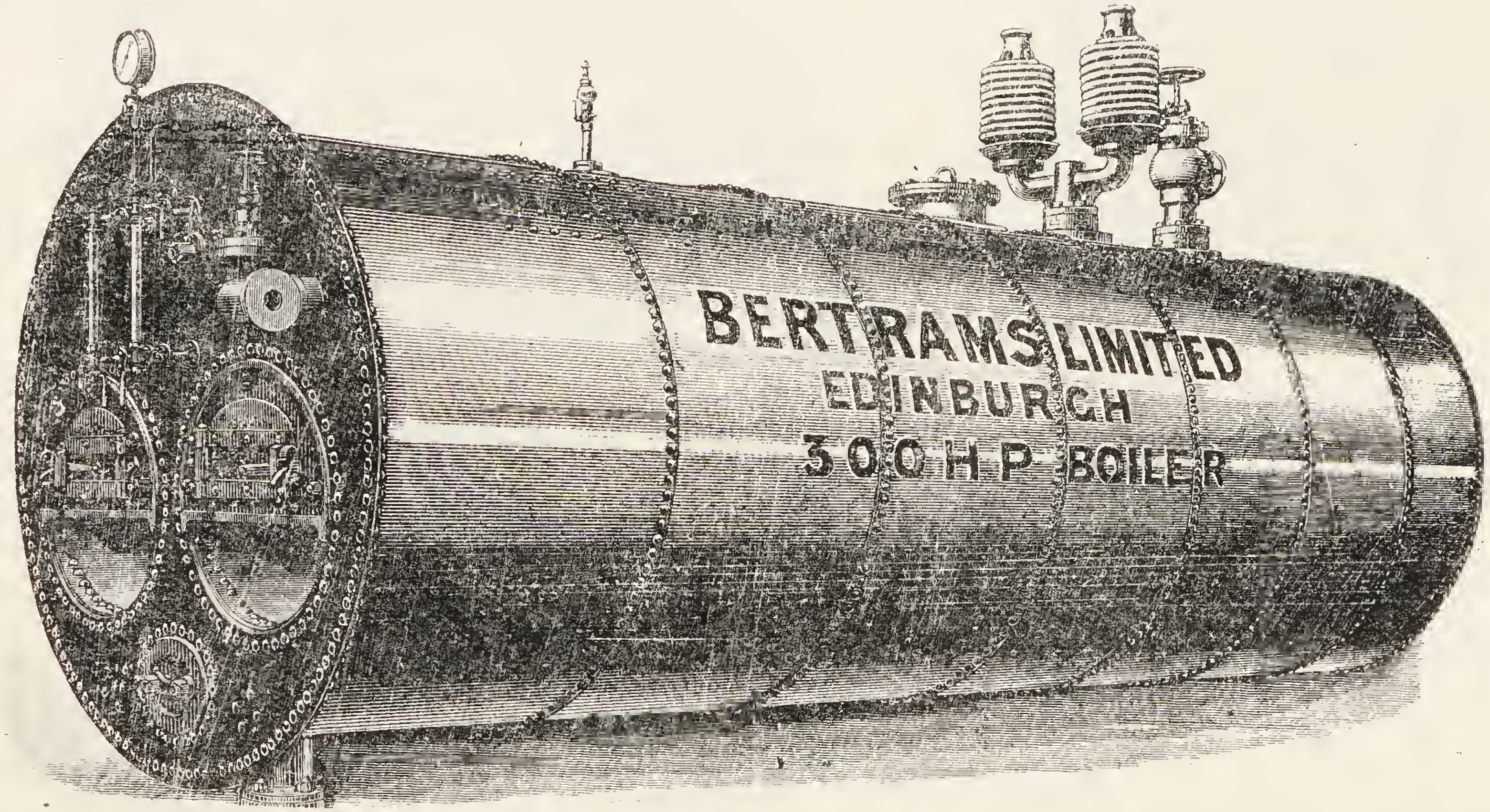

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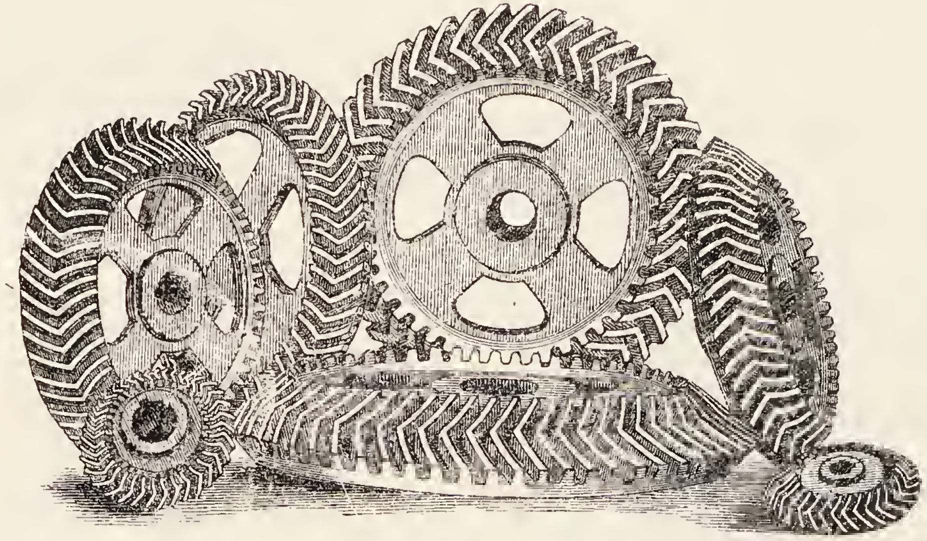

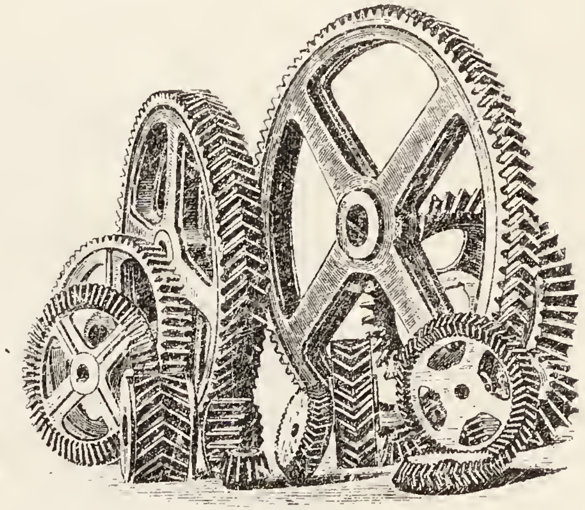

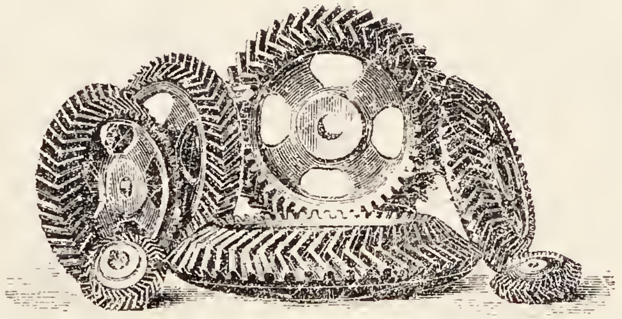

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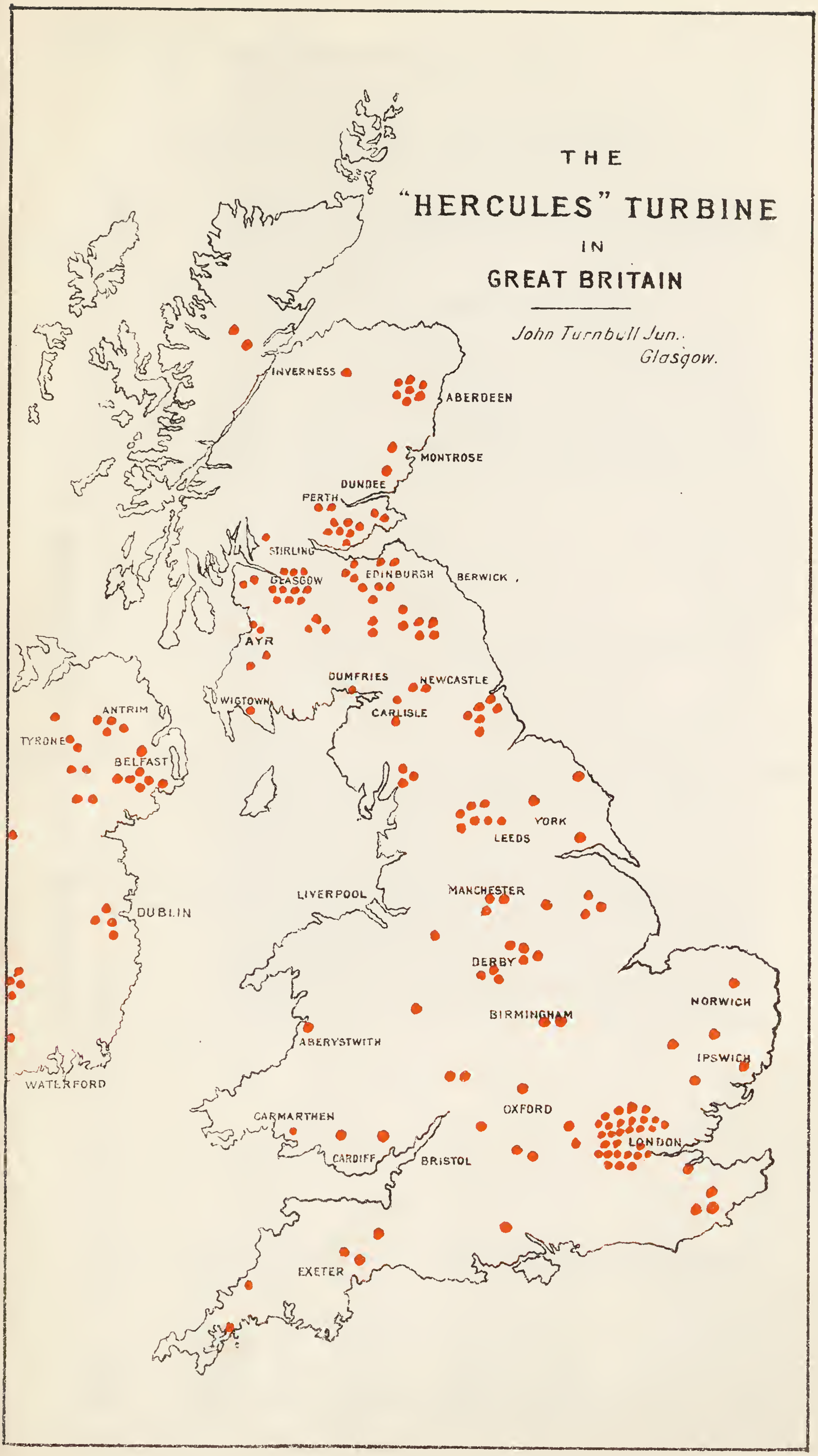

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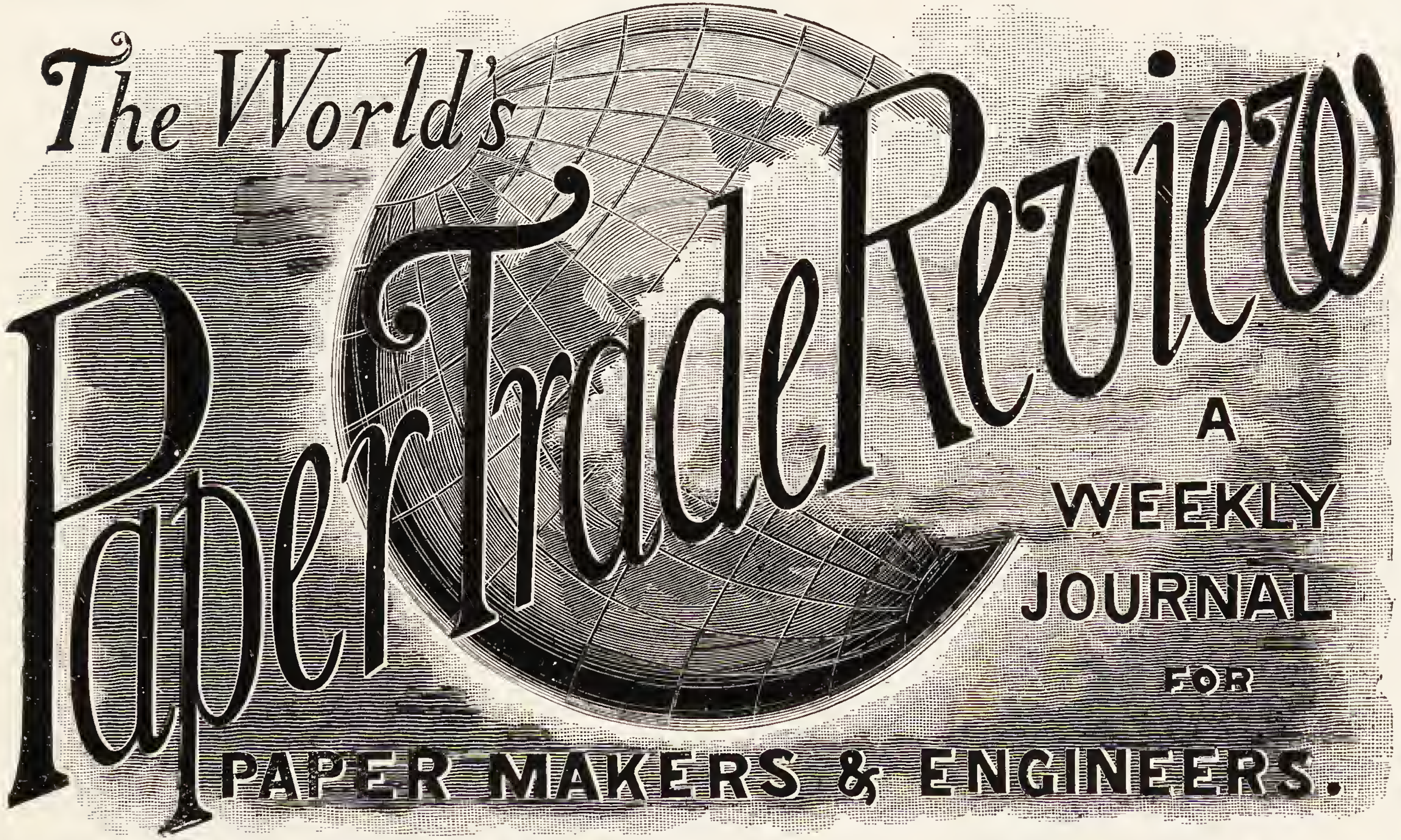

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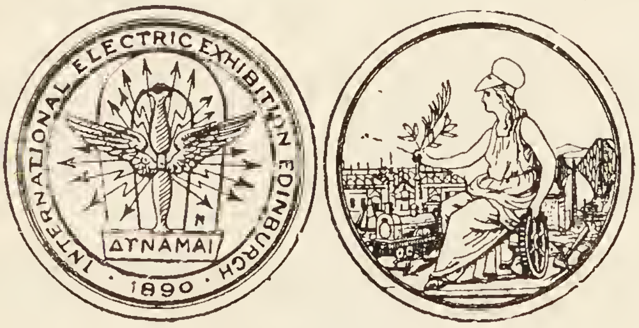

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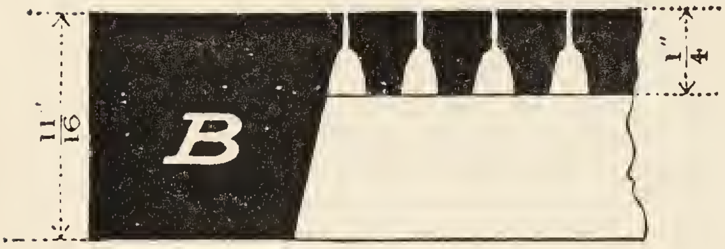

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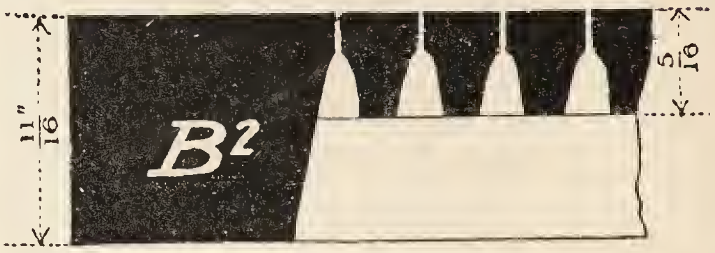

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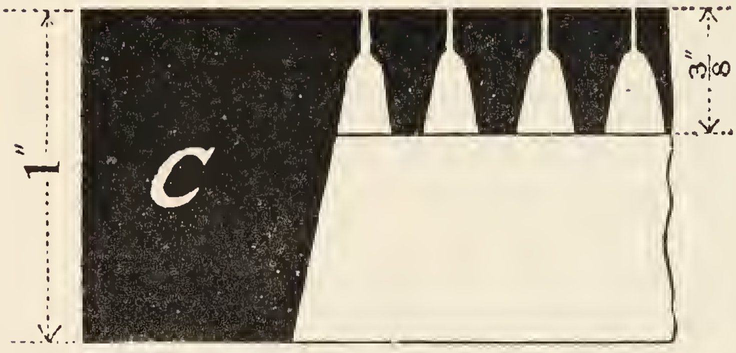

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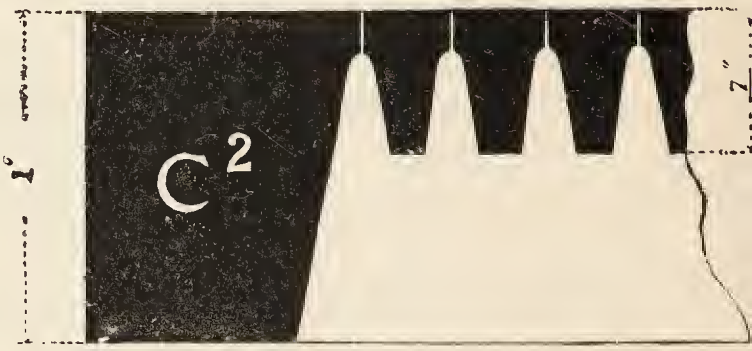

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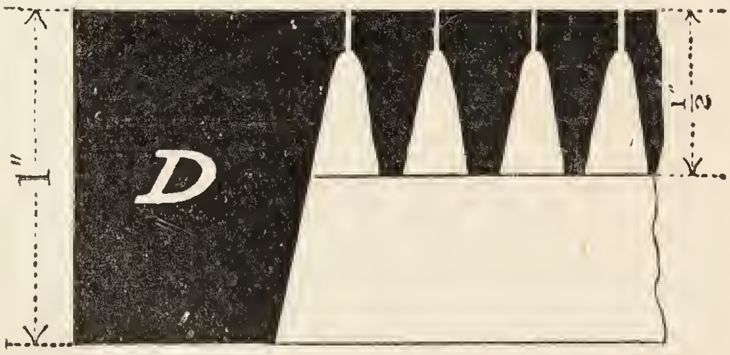

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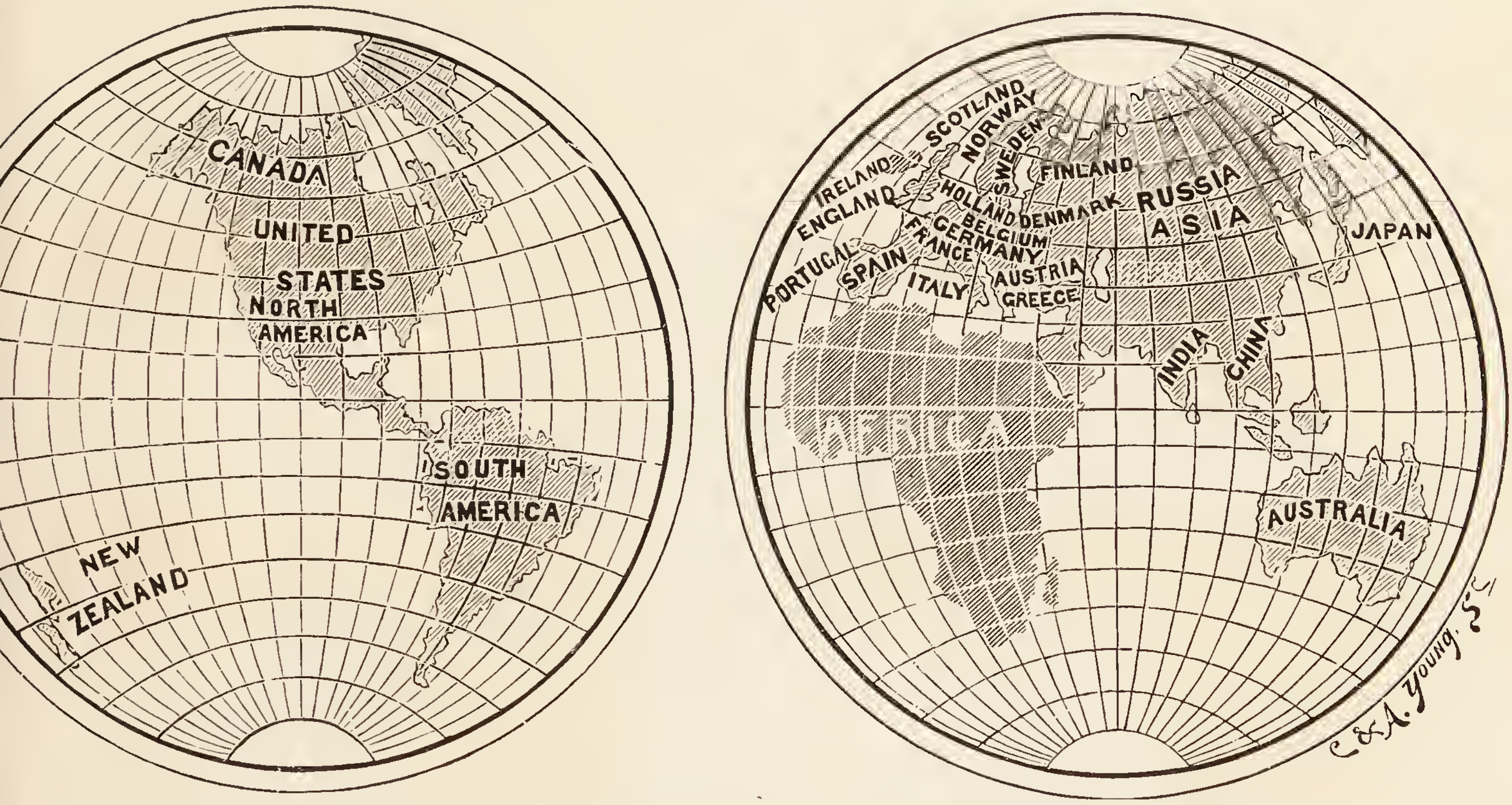

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